Volume 3 March 1957 No. 3

Canadian Aeronautical Journal

CONTENTS

Published by the

CANADIAN AERONAUTICAL INSTITUTE

Commonwealth Building, 77 Metcalfe Street

OTTAWA

AVRO CF-100 NIGHTFIGHTERS AT WORK

SERVICED AND ARMED

POISED

TAKE-OFF

ALOFT

ON DUSK TO DAWN PATROLS

The Royal Canadian Air Force nightfighter crews who fly these powerful CF-100's know that they guide one of freedom's most efficient weapons in the defence of North America and Western Europe.

•

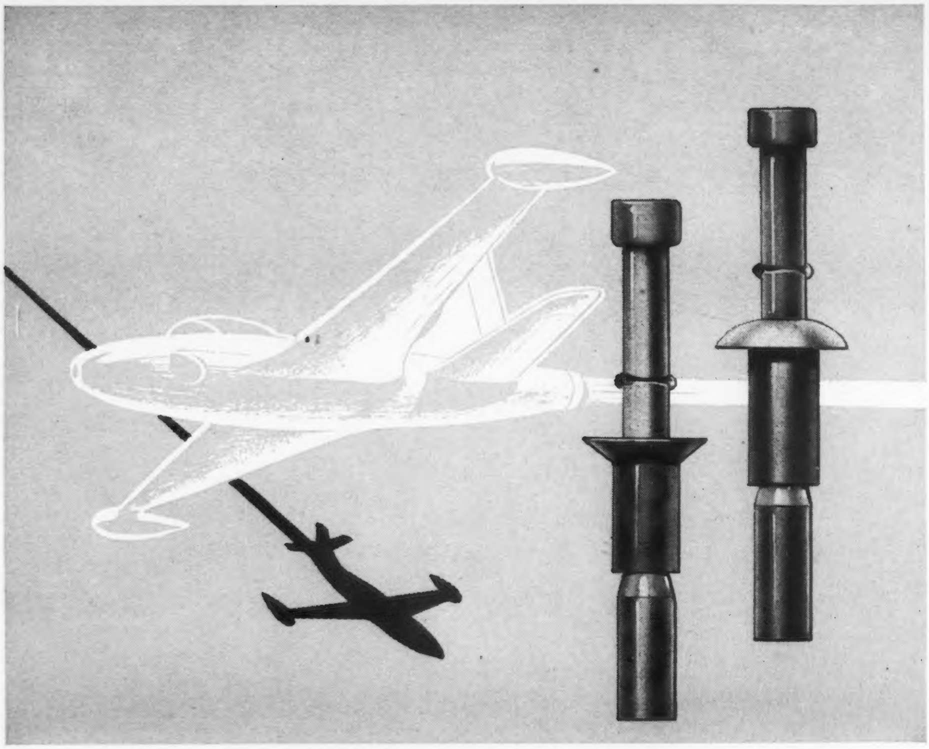
Four RCAF squadrons of CF-100's have been assigned to NATO to meet its specific nightfighter requirements.

AVRO AIRCRAFT LIMITED

AVRO AIRCRAFT

MALTON, CANADA

MEMBER: A. V. ROE CANADA LIMITED & THE HAWKER SIDDELEY GROUP



CHERRY "700"*

Aircraft Rivet

Gives More Effective Fastening

A new, more effective fastener for the aircraft industry has been developed and is now being produced at the Cherry Rivet plant in Santa Ana, California. Designated the Cherry "700," the new rivet provides a wide grip range, positive hole fill, high clinch, uniform stem retention and permits 100% positive inspection.

The "700" rivet is versatile and in many cases one length of each diameter will cover all thicknesses of material. Also, the sheet hole size is not critical as with other rivets since the design provides positive hole fill even in oversize holes. The stem always adjusts to fill the hole which affords high stem retention independent of hole size.

The manner in which the "700" rivet is set provides high clinch by drawing the sheets together tightly and uniformly. When the "700" rivet is set, the stem shoulder protrudes above the rivet head and gives visual indication that blind upset is properly formed, the sheet hole is filled and the rivet is properly set.

This latest fastener advancement is a typical example of how the Cherry Division has paced the industry with new and improved fasteners and the tools and accessories for applying them—all of which are designed, developed and produced in the Santa Ana plant.

This plant is devoted exclusively to the manufacture of products for the aircraft industry.

For information, write for the new Cherry "700" bulletin to Parmenter & Bulloch Mfg. Co. Ltd., P.O. Box 636, Gananoque, Ont.

PARMENTER & BULLOCH
MFG. CO., LIMITED
GANANOQUE, CANADA

Subsidiary of

Parmenter-Townsend Co., Ltd.

Sales Offices:

MONTREAL - TORONTO - WINNIPEG

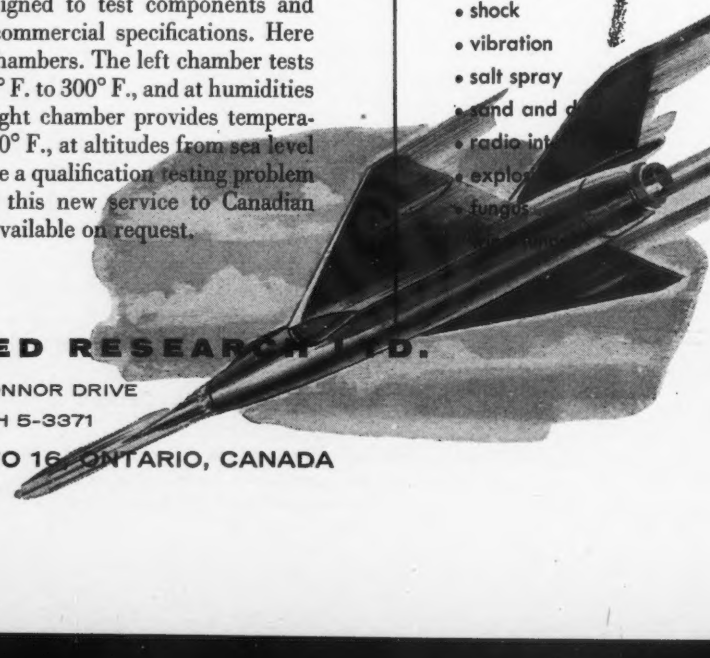
Preparing to test a Company produced rocket-firing intervalometer at −65° F. at 60,000 feet altitude

A commercial environmental test lab in Canada!

One of Canada's first privately owned and commercially available environmental test laboratories is ready now—at your service. It is designed to test components and systems to military and commercial specifications. Here are two of the many test chambers. The left chamber tests at temperatures from −35° F. to 300° F., and at humidities from 20% to 98%. The right chamber provides temperatures from −100° F. to 300° F., at altitudes from sea level to 100,000 feet. If you have a qualification testing problem write for information on this new service to Canadian industry. Quotations are available on request.

Qualification testing for your products a research problems current MIL Specs.:

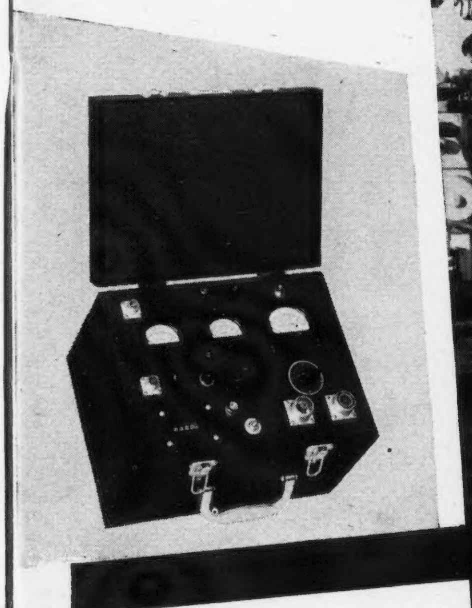
- low temperature
- high temperature
- altitude
- humidity
- shock
- vibration
- salt spray
- sand and d
- radio int
- explo
- fungus



PSC APPLIED RESEARCH LTD.

1500 O'CONNOR DRIVE
PLYMOUTH 5-3371
TORONTO 16, ONTARIO, CANADA

Part view of the machine shop at the Toronto plant of Lucas-Rotax



There is only one company in Canada with complete, self-contained facilities for design, development, quantity production and service of aircraft electrical systems and fuel systems for gas turbine engines . . . Lucas-Rotax. Out of this leadership have come such products as . . .

PORTABLE HIGH ENERGY IGNITION TESTER—designed for field testing complete gas-turbine engine high energy ignition systems. Test cycle is automatically timed and recorded.

NAVIGATION LIGHT FLASHER UNIT—specially designed for operating at extremely high altitudes and ambient temperatures, this unit weighs only 24 ozs., contains no rotating parts!

ALTERNATOR DEV 3001—provides 30KVA continuous at 8000 RPM with cooling air of 250°F. Has 84% full load efficiency. Weighs only 52 lbs.

early consultation with a Lucas-Rotax sales engineer can help you solve your aircraft engineering problems

LUCAS-ROTAX

LUCAS ROTAX

TORONTO—2200 Eglinton Avenue East, PL 5-4171 MONTREAL—5595 Royal Mount Avenue, RI 7-6509

LUCAS-ROTAX equipment used on civil and military aircraft including *CF 100, Viscount, North Star, Sabre, T33.*

CANADIAN AERONAUTICAL INSTITUTE

CANADIAN AERONAUTICAL JOURNAL

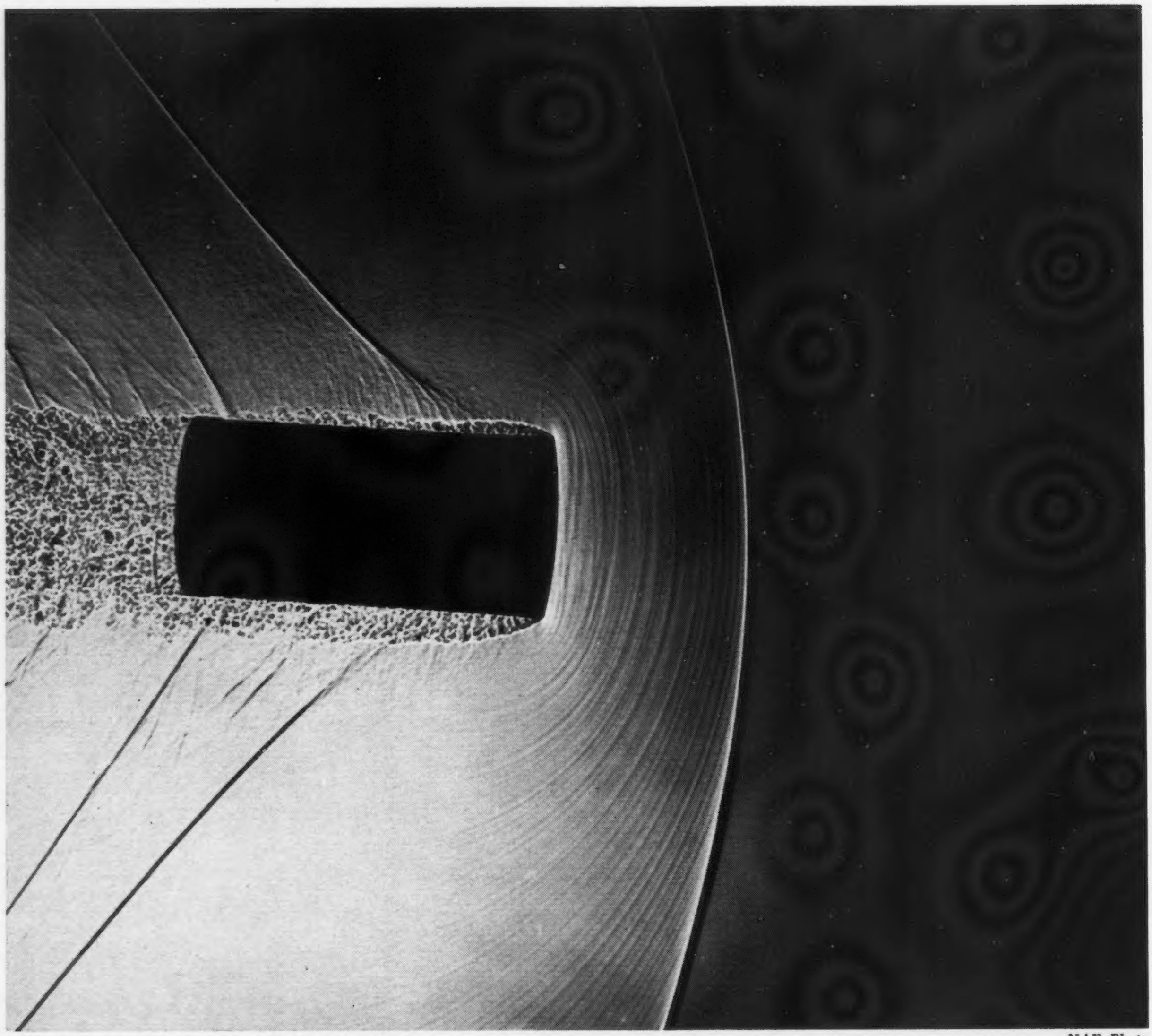
Publications Committee:
Mr. J. Lukasiewicz
S/L W. M. McLeish
Mr. G. Glinski
Mr. A. H. Hall
Editor: Mrs. G. G. Ross

Subscription—$4.00 per year. Single copy—50 cents.
Published monthly, except in July and August.
The Institute is not responsible for statements or opinions expressed in papers or discussions printed in its publications
All communications should be addressed to The Secretary. Canadian Aeronautical Institute, 77 Metcalfe St., Ottawa 4, Ontario, Canada.

Authorized as second class mail, Post Office Department, Ottawa

Printed by The Runge Press Ltd., Ottawa, Ontario, Canada

TRANSONIC MOTION



NAE Photo

Spark photograph (less than one millionth of a second exposure) of a cylindrical slug flying in air at a speed slightly above the speed of sound. The air in front of the shock wave is stationary and has not received warning of the imminent arrival of the slug. In the subsonic region behind the shock wave weak transient waves are clearly seen. Notice also flow separation at the shoulder of the slug and development of turbulent wake.

EDITORIAL

THE TECHNOLOGIST

FROM time to time, reference is made to the "missing link" in industry; to the C.A.I. he is known as the "Technologist". In Europe, the technologist has been recognized for many years; in North America he is still a "missing link" as far as the general public is concerned.

The true technologist is a part of our industrial team that we, in this country, must recognize if we are to continue our industrial growth. He is not an "almost engineer"; he should not be labelled as a person that does not have quite the intelligence to become an engineer; and he should not bear the stigma of being a "second best".

In the industrial team, he fits in between the engineer and the tradesman or routine technician. In theoretical knowledge, he approaches the engineer without being as abstract in his thinking and, at the same time, he has an appreciation of the skills of the tradesman but usually lacks the practice of application of such skills to be a proficient tradesman. He must be able to understand the problems of the engineer and the tradesman. He is the all-important link that makes possible the practical development of the ideas created by the engineer into the finished products produced by the technicians, tradesmen and production workers.

To man aircrew entirely with pilots would be a waste of training and manpower and would not produce an efficient team. In industry, we adhere to this very wasteful practice; we expect our engineers to do the work that rightly belongs to the technologists.

A great deal of this misuse of manpower is due to the lack of understanding on the part of industry and the general public. A classical example of this misuse is in the field of routine design drafting. In general, the technologist, specifically trained in this field, should do the work instead of the engineer. There are countless other jobs, including routine stress analysis, inspection, liaison between production and engineering, testing etc., that should not be done by engineers and could better be done by well trained technologists and technicians.

It is time we isolated this all-important link, the technologist, and gave him the recognition he deserves. His talents are not those of the engineer in the true meaning; he is not necessarily less intelligent; he is practical and can work with his head and his hands. He should be highlighted as an individual and not as a cast-off engineer. To bring out his individuality he should be given a title after his name but not a baccalaureate degree or an associate degree.

It is my personal opinion that his education should be as follows. He should have a high school diploma, including the Maths, Sciences and English necessary for senior matriculation. In his technical education, great emphasis should be given to furthering his studies in Maths, Sciences and English. There should be, of necessity, courses heavily weighted in the theory and allied subjects of his specialty. He should have some shop work but this should not be the predominant feature. He should, however, gain as much industrial experience as possible when not attending school. His course should be terminal; it should be narrower than the university course but it should be deep. To make his course a university credit course would broaden its scope and thus eliminate the depth necessary if he is to be of much value to an employer upon graduation. Leave university credit courses to the junior colleges.

A significant percentage of university students should be taking such a programme. The type of person who becomes an efficient technologist is one who has the ability to undertake much of the work done by engineers today. Let us not waste our engineering manpower by imposing the additional burden of the work that should be done by the technologist. Let us put engineering where it belongs and should be.

The success of automation will be largely dependent upon the technologist. As a matter of fact, the success of our future, industrially, may hinge upon our ability to produce this man, the man of the hour, the Technologist.

W. A. B. SAUNDERS
Vice-Principal
Provincial Institute of Technology and Art
Calgary

THE AIRPORT AND AIRWAYS SURVEILLANCE RADAR FOR CANADIAN AIR TRAFFIC CONTROL†

by B. I. McCaffrey*

Raytheon Manufacturing Company

"Two jet planes flying on a collision course at 500 miles per hour need to see each other two miles apart if they are to pass safely. If they are only one mile apart, and closing at a thousand feet or more a second, there is nothing the pilots can do to avoid disaster . . . ".

"Reports came from Europe that pilots of Comet airliners shuttling between London and Rome had never once seen each other even though they often passed close by. In the U.S., a jet bomber accidentally passed through a formation of what the pilot thought to be three other jets, nicking the tail of one, only to learn later than it had been a formation of six and that no one in the formation, even on the plane hit, had known of the intrusion . . . ".

" . . . fewer than seven per cent of the 300,000 trained pilots in the U.S., commercial and private, are able to fly today's bad-weather control system."

" . . . right now the U.S. has no control except around airports and when the weather turns bad. Under normal conditions every plane in the sky is allowed to fly pretty much as it pleases, controlled only by the Visual Flight Rules . . . ".

THESE excerpts from an article in the September issue of Fortune, "The Price of Air Safety", by Edmund L. Van Deusen, point up the need for better all-weather air traffic control. The increase in speed and amount of traffic aloft will make Grand Canyon crashes all too common – if we do not soon have a major overhaul.

The Civil Aeronautics Administration – shaken up a year ago by the U.S. Secretary of Commerce Weeks – has a high pressure program to do just that. The CAA, itself, is reorganizing and expanding; some 3,000 more traffic controllers and airways engineers will swell its ranks next year. It has a 246 million-dollar program to improve the country's air-traffic system which it administers. In 18 months, according to Deputy Administrator James Pyle, the CAA hopes to provide instrument facilities all over the nation for planes flying higher than 15,000 ft.

Thus, we may be able to nip in the bud a situation which threatens to become as confused as traffic on the ground – only more dangerous!

In Canada, meanwhile, there is more visible evidence of action to solve the problems. In mid 1955 the Department of Transport called for bids on Airport and Airways Surveillance Radar systems to provide almost continuous radar coverage from coast to coast. This step represents the first move in a long-range program which should give to Canada an air traffic control system second to none today and in the years to come. The installation of radar equipments is not the whole solution to the problems, of course, but it is the first necessary milestone. A brief glance at some of the problems as they exist in North America today will point to the necessity for immediate action and to the soundness of the decision by the Government of Canada to initiate a modernization program without further delay.

Speaking from experience, the writer, in travelling recently from Washington, D.C., to Boston, Mass., – normally a three-hour trip – spent six and one-half hours seated in the aircraft. More than three hours were spent in "holding patterns" and on taxi strips at touchdown points such as Wilmington and Idlewild. The problem – inadequate air traffic control facilities on the east coast for adverse weather conditions.

In the United States and Canada the rate of increase of air traffic has greatly exceeded the prediction of experts since World War II. At Toronto 533 arrivals and departures are handled daily. The same is true at Montreal. This rate is increasing at a yearly rate of twelve per cent.

At airports as remote as Gander, Newfoundland, 100 aircraft land and take off daily; arriving from and departing for overseas points. This traffic cannot be nicely spaced to share the full 24 hours of the day. Owing to the distances travelled, all aircraft would like to arrive and depart at the same time and would like to take advantage of the same favorable winds and altitudes. Canada's responsibility in handling such traffic to and from the United States extends from Newfoundland

†Paper read at the I.A.S./C.A.I. International Meeting in Toronto on the 27th November, 1956.
*Project Engineer.

across the Maritimes to the U.S. border. Responsibility does not decrease when adverse weather prevails.

Of course, airborne equipment such as anti-collision radar, radio altimeters, beacons and other electronic devices may have their places in the solution of the air traffic problem. However, whatever the means, the ultimate solution must be a system which prevents aircraft from flying into each other without, in any way, impeding progress to their destinations.

The seriousness of airline traffic has become more acute with the advent of the jet aircraft with its great speeds and excessive low-altitude fuel consumption. Some advocate that the answer to the problem will require continuous traffic control of all aircraft from the loading point at one runway to the unloading point at the next. All solutions, be they operated by automatic computers in the future or manually by human operators today, require a precise knowledge of aircraft positions. The obvious answer for a device for providing the necessary data collection is surveillance radar with sufficient long-range capabilities to give the ground control facility adequate time for efficient scheduling of the traffic into and out of the airway terminals.

The equipment specification, written by the Department of Transport, covering the Airport and Airways Surveillance Radar indicates very clearly the requirements for equipment which is to see uninterrupted duty for many years and whose purpose it is to provide an aid to safety of human life. Four basic factors are involved. These are performance, reliability, ease of maintenance and long life with continuous operation.

PERFORMANCE

The most important performance characteristic of a search or surveillance radar system is its range performance – its ability to determine the presence of a target at great distances. Of slightly lesser importance is resolution – the ability to separate one target from another. Another important feature is the ability to differentiate targets from ground and precipitation clutter so that performance is not affected by the location of the system nor by conditions of weather. The performance of a radar system can be predicted very accurately by use of the "radar equation" which is written as follows:

$$R^4 = \frac{P\,G^2\,\lambda^2\,\sigma}{(4\pi)^3\,K\,T\,B\,F\,S}$$

R = Range, Meters
P = Power, Watts
G = Antenna Gain (one way)
λ = Wavelength, Meters
σ = Target Radar Cross Section, Square Meters
K = Boltzman's Constant, 4×10^{-21}
T = Absolute Temperature, ° Kelvin
B = Receiver Bandwidth, Cycles/sec = 1.2τ where τ = pulse length, seconds
F = Noise Figure
S = Integration Factor (See below)

In designing a radar equipment, the engineer has some latitude in the selection of the parameters for this equation. For others, he has no choice whatsoever; viz., target size, Boltzman's constant and the absolute temperature. He has very little control over the integration factor, S, and must, in all realistic calculations, apply it in the range equation. This factor takes into consideration the differences between theoretical and observed radar performance. It accounts for such losses as operator fatigue and the amount of degradation which an equipment might suffer under normal conditions without being noticed by the operator. It is a legitimate and necessary factor to include, for the ability to detect targets certainly depends on the particular operator and the environmental conditions. Experience has shown that for a good operator and a PPI, under good conditions, a figure of 2 or 3 db appears reasonable. The integration factor also includes a beam shape factor, which allows for the fact that not all of the pulses received between the half power points are of the same strength. System losses, which result from unavoidable design tolerances on such parameters as bandwidth, are also included. It is necessary to include the above "losses" in the "radar equation" in order to arrive at a realistic prediction of radar performance, for these losses decrease the relative strength of signals which are wanted and the noise which is unwanted. It is the decrease of the ratio of signal to noise which limits our ability to see the weak signals returning from distant targets. It is this condition which prevails in a television receiver when "snow" (noise) obliterates the picture.

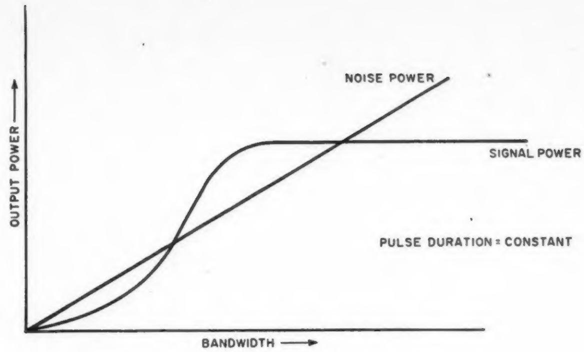


Figure 1
Effects of bandwidth on signal power and on noise power

In using the radar equation to predict performance, it is normally assumed that all parameters are optimum. However, in the practical case, design limitations on components yield something short of optimum. For example, the bandwidth of the receiving system is normally designed to be $2/\tau$ instead of $1.2/\tau$,[a] the optimum value. Figure 1 shows the relative effects of bandwidth on signal and on noise. Signal power reaches a maximum value while noise increases linearly with bandwidth. The system loss which results from this consideration is discussed below using the actual AASR parameters. That the losses in a system have considerable effect on the performance is shown by the graph of Figure 2. The above discussion of system losses and degradation is presented for a number of reasons, which

[a]It can be shown that the parameter "B" in the "radar equation" can be replaced by $1.2/\tau$ where τ is the duration of the transmitted pulse. The reader is referred to the bibliography for a detailed discussion of the subject of signal and noise.

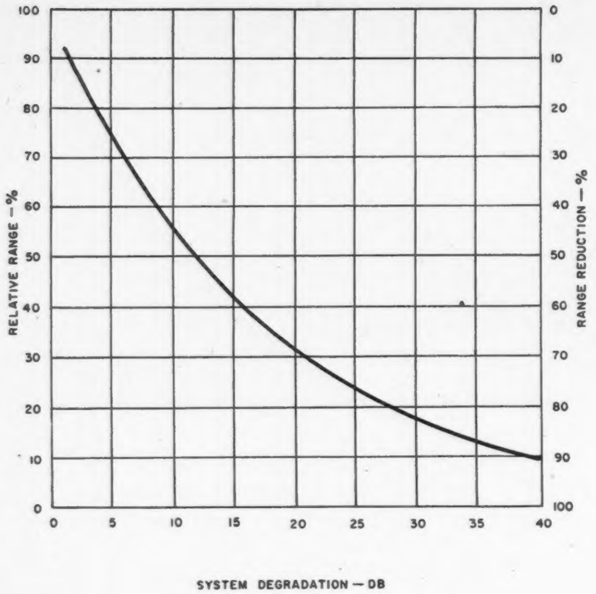


Figure 2
Relative range vs system degradation

will become clearer during later discussions of the AASR equipment design.

Perhaps a more obvious approach to the design of a long-range radar system would be to make all parameters in the numerator as large as possible. The value selected for the peak power, P, of the transmitter is limited only by the availability of suitable components. However, it is to be observed that doubling the magnitude of P has no greater advantage than that of reducing the system losses by a factor of two.

For purposes of AASR, selection of the magnitude of the transmitted power was governed to some extent by the availability of a magnetron (transmitter tube) with which we have had a great deal of production experience not only from its use in equipment of our own design, but also from its use in commercial and military equipment built by other manufacturers.

Selection of the parameters, G (the antenna gain) and λ (the wavelength of the radiation), must be considered together. The product, $G\lambda$, must be as large as possible to attain maximum range performance. For example, the Department of Transport specification permits the use of either a 10 cms (S-Band) or a 23 cms (L-Band) wavelength. All other things being equal, the choice of L-Band will result in a range performance greater by the fourth root of five, or by 50 per cent, compared with S-Band. There are other factors which make L-Band a better wavelength for long-range surveillance radar, one of which is that attenuation through rain is much less, permitting easier viewing of aircraft through storms.

The choice of L-Band is not made, however, without paying a price. In stating the advantages inherent with L-Band operation, it was assumed that "all other things" were equal. In order to have the same antenna beamwidth and gain at L-Band as at S-Band, for example, the L-Band antenna must have five times the area as the equivalent

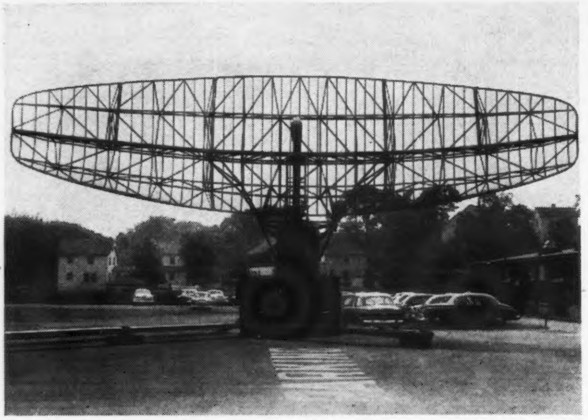


Figure 3
Raytheon 40 ft antenna, front view

antenna at the shorter wavelength. The design of an antenna of sufficiently large dimensions, which would still withstand the wind and ice conditions likely to occur during the life of the AASR system, is not a small task. However, at the time of bidding for the AASR contract, Raytheon Manufacturing Company had just completed the design and testing of a large L-Band antenna eminently suitable for the purpose and having a beamwidth much narrower than the 2.5 degrees specified. Dimensions of the reflector of the antenna are 40 feet long by 11 feet high (Figures 3 and 4).

Under some conditions of siting, the longer wavelength does have a disadvantage which is not so noticeable at the shorter wavelength. This is the phenomenon known as lobing. Lobing is caused by propagation of energy over a reflecting surface. If the transmission path lies near a reflecting surface, it may be possible for

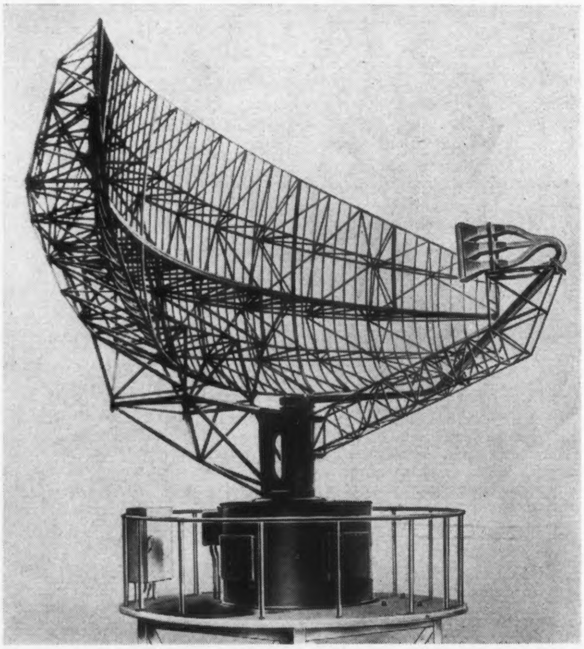


Figure 4
Raytheon 40 ft antenna, three-quarter view

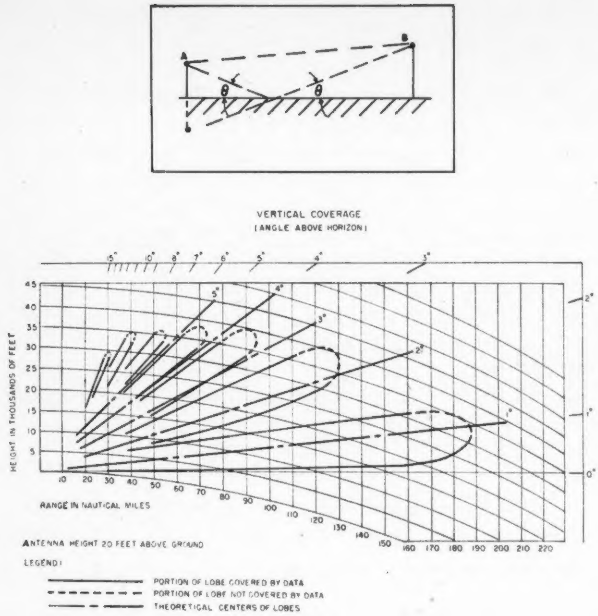


Figure 5

Lobes in vertical radiation pattern caused by interference of direct and reflected waves, insert shows geometry

energy to reach the target and hence for scattered energy to return to the radar antenna, by way of the surface as well as directly. The result of combining the direct and the reflected wave at the target will depend on the relative intensity and phase of the reflected waves, which, in turn, will depend not only on the difference in the path lengths but also on the changes of phase or intensity introduced in the process of reflection. Figure 5 shows the geometry of the lobing phenomenon as well as the resulting antenna pattern.

However, the performance of the AASR which Raytheon will deliver to the Government of Canada will equal the maximum range of any competitive S-Band set, even at the lobe minima. In the lobe maxima, the L-Band range will be great, even against an F-86. The long range permits excellent tracking and, even though the airplane is lost occasionally in minima, enough data will be obtained at long range to permit maintaining contact — the AASR is for use against friendly aircraft which will not be making evasive maneuvers.

The ability of the eye to detect a target on the radar indicators is dependent on the number of pulses striking the target during the time the antenna is scanning it. The number of scans is dependent on the pulse recurrence frequency, antenna horizontal beamwidth, antenna rotational speed and the speed and direction of the target. Accordingly, any one of these factors cannot be considered without reference to the others. For example, for early warning out to 150 miles, the practical upper limit for pulse recurrence frequency is about 400 pulses per second. With the pulse rate and beamwidth fixed, the ability to detect an object becomes dependent on the antenna rotational speed and the movement of the target. In general, slower antenna speeds increase the ability to detect weak targets, for at slower rotational speeds the antenna dwells for a longer time on the target. On the other hand, if the antenna is turning at too slow a rate, a fast-moving aircraft might travel such a distance while the antenna makes one revolution that identification of a particular target might be lost amongst others during heavy traffic conditions (Figure 6).

The results of such considerations are manifest in the final design of the AASR which is discussed below in detail.

The prediction of the performance of the AASR is based on the unprecedented experience, in the application of surveillance radar, of the field use of more than 1000 AN/TPS-1D systems and the subsequent tested performance of its successor, the AN/FPS-19. When combined with the Raytheon Forty-Foot Cosecant Squared L-Band antenna, the customer's requirements will be surpassed in several ways. Table 1 lists the specified parameters and compares them with the performance which the AASR will provide.

TABLE 1

Performance Characteristic	D.O.T. Specification	Raytheon's AASR
Range	90 N.M. against F-86	88 N.M.
Distance Resolution	1500 ft.	1000 ft.
Azimuth Resolution	2.5° against F-86	1.4° against F-86
Subclutter Visibility	20 db @ 20 miles	27 db @ 20 miles
Precipitation Clutter Cancellation	Required but not specified	20 db I.C.R.
Antenna Pattern	CSC^2 to 18°	CSC^2 to 60°
Antenna Rotation Speed	6 to 12 rpm	6 to 12 rpm

MEASURED PERFORMANCE CHARACTERISTICS

The coverage of the AASR equipment will, by virtue of the high-gain antenna, exceed that of Figures 7 and 8 by a factor of almost 2. Figure 7 shows the coverage of the AASR using a CSC^2 16-ft antenna for a 50% blip/scan against an incoming single engine propeller

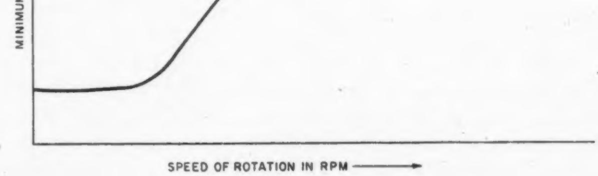


Figure 6

Effect of antenna rpm on minimum detectable signal (MDS). The smaller the MDS the better the radar.

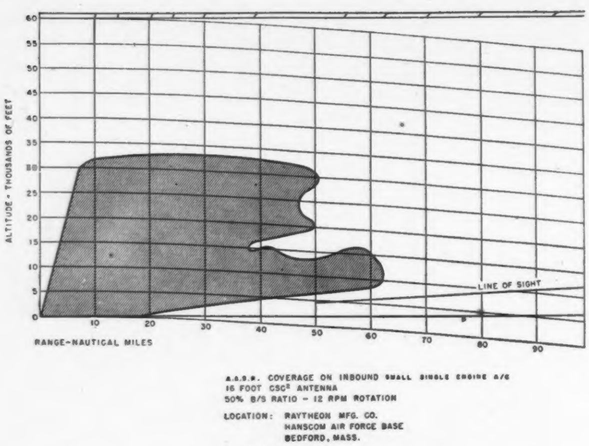


Figure 7
Average coverage of AASR with 16 ft CSC² antenna

airplane. Coverage to 62 miles is obtained on the antenna beam, whereas the minimum coverage, owing to a small lobing effect, is 38 miles. The lobing is slight because the lower cutoff of the antenna beam is sharp, causing small illumination of the ground and consequently producing only small interference of the direct radiation by reflected energy.

Figure 7 is derived from a large quantity of data, a sample of which is given in Figure 8. Fourteen runs were made at seven different altitudes. The signal return on each antenna scan is depicted by a vertical line of a length chosen to indicate the observed signal strength, a "0" being used for no signal. This figure shows, for example, that, for a single engine propeller aircraft coming in at 25,000 ft, the signal is consistently good within a 45-mile range.

Figures 7 and 8 show the actual coverage of the AASR with a 16-ft antenna. The 40-ft antenna has a one-way gain superiority over the 16-ft antenna of 5 db. Thus, with the large antenna, other things being equal, the range will be almost doubled over that shown by the figures. The improved performance due to the use of the 40-ft antenna was calculated and is shown by Figure 9. This performance is extrapolated from the known high-probability detection range of 90 miles against a four-engine aircraft with the 16-ft antenna. The actual pattern of the large antenna was used. Lobing was neglected. Lobing will decrease the range somewhat at some elevation angles, while improving it at others. By judicious orientation of the beam, the relative effect of the destructive interference will be no worse than that shown in Figure 7.

CALCULATED PERFORMANCE CHARACTERISTICS

The coverage determined above, extrapolated from experimental results, is in agreement with theory. The range against a small fighter, taken as 1.5 square-meter average cross-section, is calculated for a 50% probability of detection using the following parameters:

P = 600 kw (peak power)
τ = 2 μsec (pulse length)
PRF = 400
G = 35 db[b] (3000 X) (nominal one-way antenna gain)
λ = 23 cm (mid-band wavelength)
F = 9 db (8X) (receiver noise figure)
B = 1 mc (receiver bandwidth)

With a 6-rpm antenna scan rate, the 1.4 degree beam dwells on the target for $1.4/360 \times 10$ or 0.039 seconds

[b]Minimum specified gain for 2305A antenna is 34 db.

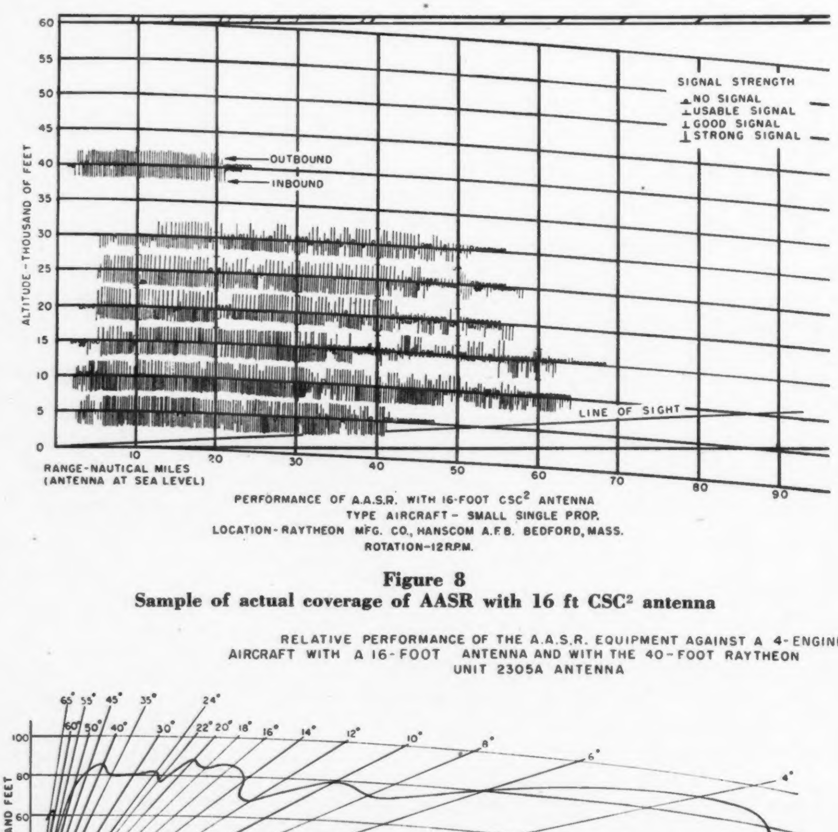


Figure 8
Sample of actual coverage of AASR with 16 ft CSC² antenna

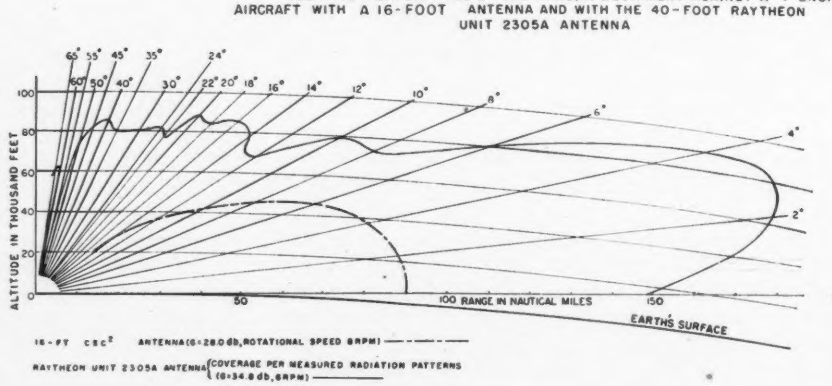


Figure 9
Coverage of 40 ft antenna vs 16 ft CSC² antenna

in each scan. Thus, the number of pulses integrated in one scan is 0.039 × 400 or 15. For a probability of detection of 0.5, and neglecting other effects, the signal-to-noise ratio must be +3.8 db.

The following losses must be allowed: a loss of 1.6 db for beam shape, a "collapsing" loss of 2 db, a loss due to the non-optimum receiver bandwidth of 0.6 db, a loss due to fluctuation of echo amplitude of 2 db, and an "operator factor" of 2 db. These losses total 3.8 + 1.6 + 2.0 + 0.6 + 2.0 + 2.0 or 12.0 db or 16 times. This is the signal-to-noise ratio required for the specified probability of detection and is denoted by S below.

From the "range equation":

$$R^4 = \frac{PG^2 \lambda^2 \sigma}{(4\pi)^3 KT \frac{1.2}{\tau} FS}$$

$$= \frac{6 \times 10^5 \times 9 \times 10^6 \times 0.053 \times 1.5}{2 \times 10^3 \times 4 \times 10^{-15} \times 0.6 \times 8 \times 16}$$

$$= \frac{4.3 \times 10^{11}}{615 \times 10^{-12}} = 7.0 \times 10^{20}$$

$$R = 1.63 \times 10^5 \text{ meters}$$

$$= 88 \text{ nautical miles}$$

The value of 1.5 square meters used in the above calculation is considered representative for small jet fighters. Since allowance is made for losses that are often neglected in the range calculation, the 50% probability detection range of 88 miles is realistic. Solid display will not occur, however, until the probability approaches unity. As an example, for an 85% probability of detection, an increase of 5.2 db in signal strength over that required for 50% probability detection is required. This increase will take place at a range of 74% of 88 or 65 miles. For such a small target, almost solid display at 65 miles is excellent performance.

It should be noted that if one uses the simple but inexact criterion for detection, that the signal-to-noise ratio be unity, and take a cross-section of 0.3 square meters (the definition of an F-86 given in the Department of Transport specification) the range calculates as follows:

$$R^4 = \frac{PG^2 \lambda^2 \sigma}{(4\pi)^3 KT B F}$$

$$= \frac{6 \times 10^5 \times 9 \times 10^6 \times 0.053 \times 0.3}{2 \times 10^3 \times 4 \times 10^{-15} \times 1 \times 8}$$

$$= \frac{0.86 \times 10^{11}}{64 \times 10^{-12}} = \frac{860 \times 10^8}{64 \times 10^{-12}}$$

$$= 13.4 \times 10^{20}$$

$$R = 1.91 \times 10^5 \text{ meters}$$

$$= 103 \text{ nautical miles}$$

Note the effect of the parameters "S" and "σ" in the above equation. By virtue of the factor "S", the resultant range in the first of the above computations is substantially less than that in the second, even though the radar cross-section in the first case is five times that of the second. In view of this, it is obvious that the

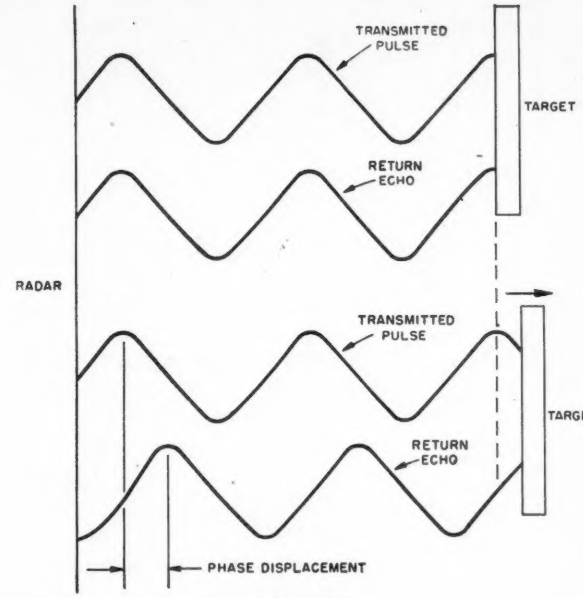


Figure 10
Phase relationship of transmitted signals vs echo signals

degree of significance of σ is dependent largely on the radar equation used. It is also evident, therefore, that comparison of the performance capabilities of different radar systems is meaningful only when the same radar equation is applied to the compared system.

MOVING TARGET INDICATION (MTI)

In all radar systems, the received RF signal voltage bears a definite phase relationship to the RF voltage of the corresponding transmitted signal. The phase relationship is dependent on the distance between the radar antenna and the target (Figure 10).

In general, fixed objects produce echoes which have a fixed phase relationship from one receiving period to the next, whereas moving objects produce echoes which have a different phase relationship from one receiving period to the next. It is on this principle that the MTI circuits are arranged to discriminate between fixed and moving targets.

The ability of the MTI to detect moving targets or to differentiate between fixed and moving targets is dependent on several factors. If the moving target is in the area free from clutter (fixed targets), the main limiting factor is the optimum relative speed of the target with respect to the radar antenna, i.e., the radial velocity of the target.

Figure 11 shows the relationship of the amplitude of MTI video signals developed (before video limiting) versus the speed of the target. Blind spots (no signals) appear at relative speeds of 89.4 knots and integral multiples thereof. It should also be noted that maximum MTI signals are developed at speeds of 44.7 knots removed from the blind speeds. The values given are approximate for a transmitted wavelength of 23 cm (L-Band) and a pulse recurrence frequency of 400 pulses per second.

The first blind speed, or velocity at which the re-

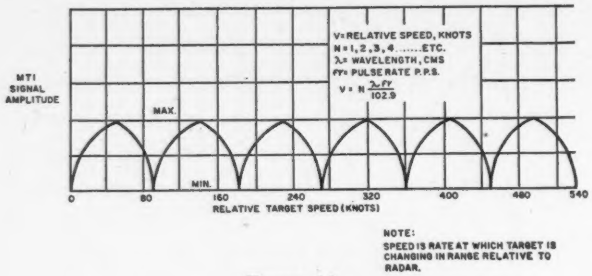


Figure 11
MTI Signal amplitude vs relative target speed

sultant MTI video signal is zero, for other values of wavelength and pulse repetition rate can be determined from the formula:

$$V = \frac{N \lambda f}{102.9}$$

where V = blind speed of target, knots
λ = wavelength transmitted, centimeters
f = pulse recurrence frequency, pps
N = 1, 2, 3, 4, . . . etc.

It is of interest to note that the above formula points out the obvious superiority of L-Band over S-Band for MTI applications. At S-Band more than twice as many blind speeds will occur.

CIRCULAR POLARIZATION

Radar is susceptible to interference by rain and other forms of precipitation, detecting and displaying them as it does aircraft. This precipitation return can mask or clutter the radar scope, preventing the detection of aircraft. The need to detect aircraft despite this clutter is obvious. Increase in air-traffic density because of bad weather stacking and holding makes it even more imperative to have good aircraft detection. Operation of Circular Polarization is based on the synthesis of a circularly polarized wave by two waves, one 90 electrical degrees behind the other, linearly polarized at right angles to each other, and propagated in the same direction (Figure 12).

Effective discrimination of circular polarization against rain return, as compared to discrimination against aircraft return, is due to the spherical symmetry of raindrops. A circularly polarized wave incident upon a spherical raindrop is reflected as a circularly polarized wave. If the raindrop is nearly spherical, the reflected wave is nearly circularly polarized. A right-handed circularly polarized wave becomes left-handed when it is reflected from a symmetrical reflector, just as the reflected mirror image of a right-handed machine screw appears to be left-handed. An antenna which originates an outgoing right-handed circularly polarized wave cannot respond to the incoming left-handed wave from the raindrop; cancellation is complete if the raindrop is spherical and less than complete if the raindrop is not spherical.

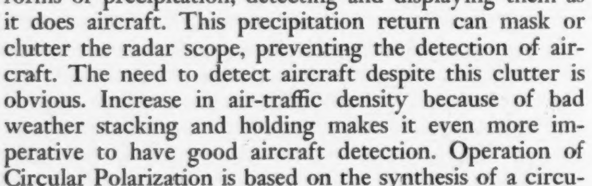


Figure 12
Circular polarization for reduction of precipitation clutter

Since an aircraft is not a symmetrical reflector, it scrambles the polarization of the wave it reflects. This scrambled polarization contains some of the same polarization as the incident wave. As the antenna that originated the incident wave can respond to this component, although there is some loss, the aircraft will be "seen" by the radar with considerable advantage over the precipitation return.

A suitable figure of merit for circularly polarized radar antennas is Integrated Cancellation Ratio. This is defined as the ratio of received signal energy obtained with circular polarization to received signal energy with linear polarization, with the antenna in both instances completely surrounded by an infinite number of randomly distributed small spheres. With care, Integrated Cancellation Ratios of 20 db can be obtained with large reflector type antennas.

In order to take advantage of the above principle, the AASR provides circular polarization for adverse weather operation and linear polarization for normal operation. Selection of either polarization is made remotely by the ATC Radar operator by means of a switch which actuates a changeover mechanism at the antenna.

VIDEO MAPPING GENERATOR

Having designed MTI into the AASR to remove the unwanted return from fixed ground objects, special means must be provided to display a few identifying landmarks on the radar scope to assist the radar operator in his duties of air traffic control. To do this, a further refinement for the AASR is the incorporation of a video mapping generator for superimposing special map and terrain features on the plan position indicators of the operators' consoles. A simplified sketch showing the method by which this is achieved is shown in Figure 13.

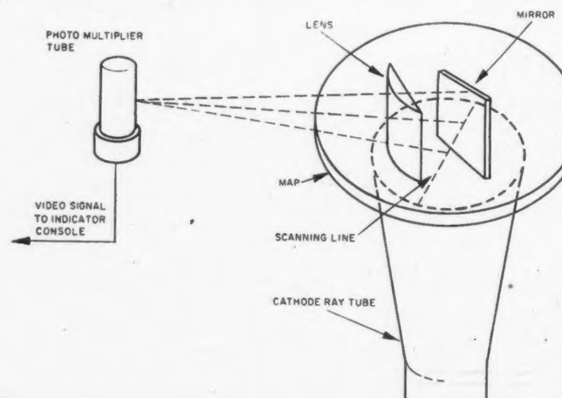


Figure 13
Simplified sketch of map scanning system

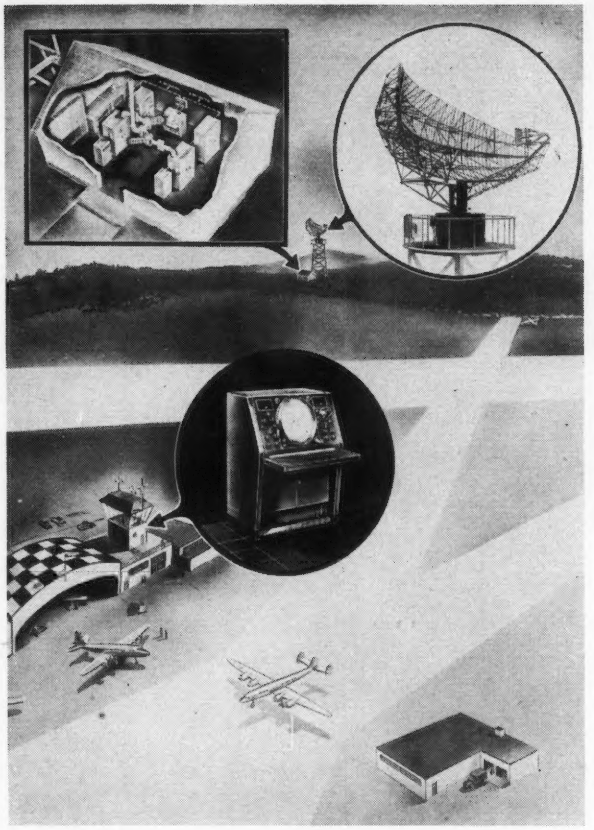


Figure 14
AASR installation pictorial

The map is rotated and its azimuth is synchronized with the antenna rotation. Sweep speed is adjusted to correspond to the scale of the map in use. To obtain maximum definition for the size of cathode ray tube used, the sweep is started at one edge of the tube face and is swept across the entire diameter of the tube. The sweep is stationary with the map being rotated around the start of the sweep as its center. The map, which is opaque with transparent lines, allows light to pass through when the sweep is at a point corresponding to a line on the map. The mirror/lens combination is used merely to make a compact assembly.

In the preceding pages some of the factors affecting radar performance have been discussed. In what follows, details of the equipment are described which ensure that the specified performance will be achieved. At the same time, emphasis is placed on the means by which the important qualities of reliability, ease of maintenance and long life with continuous operation are designed into the system.

GENERAL

The Airport and Airways Surveillance Radar equipment is a dual channel radar system (Figure 14). The transmitter and receiver portions of the equipment are located adjacent to the antenna in a small building especially designed for the purpose. Basic design of the system requires that remote control of the units within this building be possible at the operator's station up to two miles away. Thus, the antenna can be erected at an optimum location for long-range surveillance and still have the operator's console located at the control tower. Accordingly, within the airport control tower, a Master Console Indicator is provided with sufficient remote control facilities to operate either of the transmit/receive channels. Operation will normally function with one transmitter feeding the antenna while the other remains in a warmed-up standby condition ready for instant operation if a failure occurs in the radiating channel. By the mere actuation of a switch, the remote operator can change from one channel to the other. Remote controls include tuning and gain controls, selection of circular/linear polarization, antenna stop-start, antenna rotational speed control and many other system functions.

PRODUCT DESIGN

The structural strength and rigidity of the cabinets and consoles described below and illustrated in Figures 15 through 24 are such that normal handling in loading, shipping, unloading and setting into position for installation will not result in any permanent set or deformation to impair the appearance of the cabinets or to interfere with the ease of maintenance, removal of units and components, ventilation and operation of access doors. The structural strength and rigidity of the units is independent of any strength and rigidity furnished by access doors. The design of all units provides ready accessibility for maintenance and repair. It is not necessary to remove any chassis or assemblies from their cabinets for maintenance or repair of components. If any chassis or assembly is to be removed at any time, it can be done easily and without requiring the removal of any other chassis or assembly.

Product design is arranged to provide accessibility for the maintenance technician to units in the order in which maintenance functions would be performed. For example, meters and circuit breakers which bear evidence of status or system performance can be viewed through windows in the access doors. Upon opening the doors, tubes and test points are immediately accessible. Then, by releasing hold-down bolts, the chassis are able to swing forward and out for servicing when required. It is not necessary to use special patch cords and test boxes for making electrical measurements. Cabinets are fitted with doors on front and on rear for maximum accessibility.

Figure 15

Sufficient forced ventilation is provided and the density of packaging is such that the maximum temperature rise above ambient

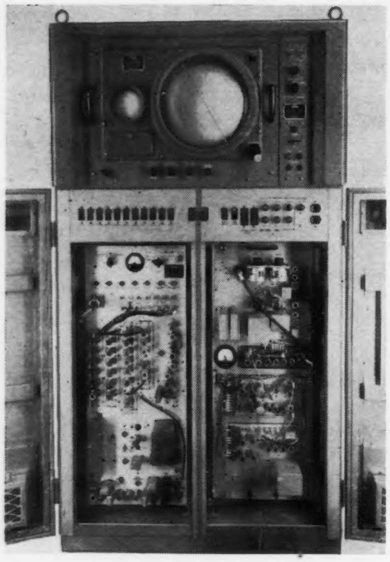


Figure 16

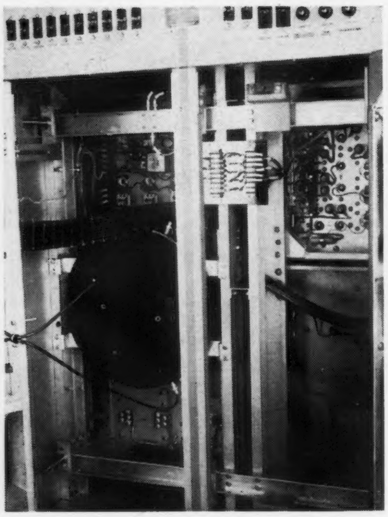


Figure 17

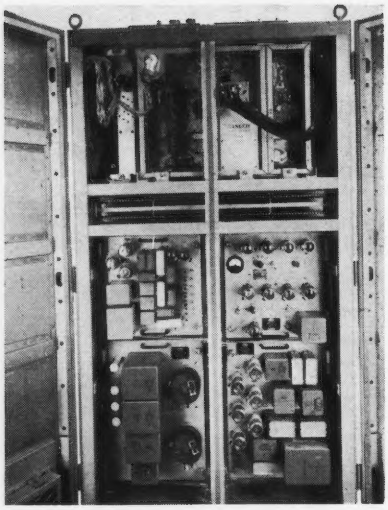


Figure 18

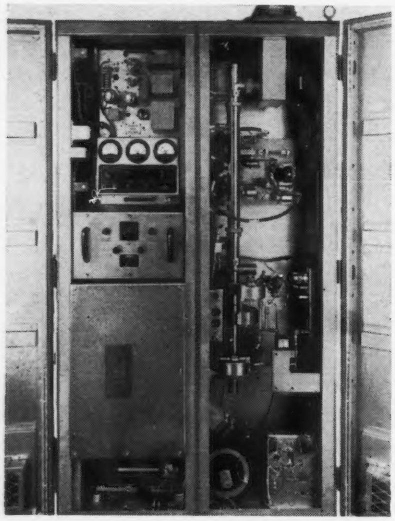


Figure 19

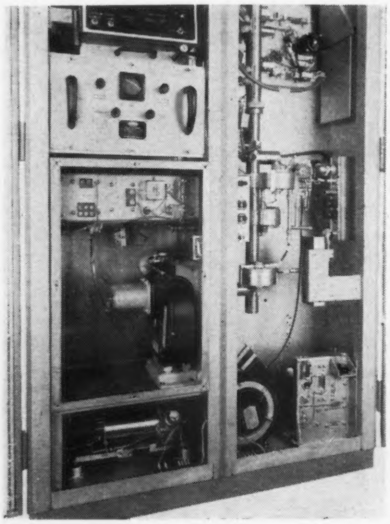


Figure 20

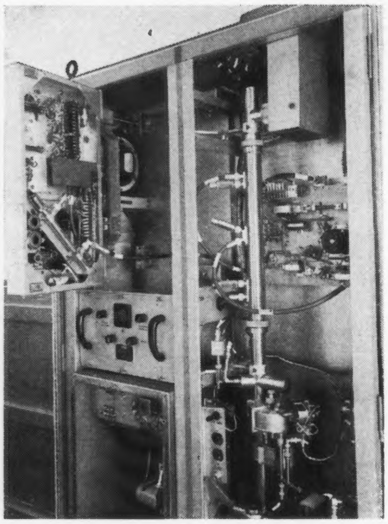


Figure 21

throughout the equipment is 10°C. Each cabinet has four blowers and air is filtered before entering the cabinets.

Figure 15 shows an AASR cabinet with all doors closed. Figure 16 shows the Indicator/Comparator cabinet with front doors open. The Signal Canceller and receiver chassis is at the left with a unit of the performance monitor on the right. In Figure 17 these two chassis have been swung out to make accessible the quartz delay line and portions of the performance monitor. In Figure 18 the same cabinet is shown with the rear doors open exposing the power supply tubes.

In Figure 19 the doors of the transmitter cabinet are open exposing the RF plumbing on the right and the performance monitor meters, monitor scope, magnetron compartment and local oscillator on the left. The next two Figures (Figures 20 and 21) show the same cabinet with magnetron compartment open. In Figure 21 the performance monitor chassis is swung outward to expose the wiring.

Figure 22 is a photograph of the transmitter cabinet with the rear doors open and with compartment covers removed to show the easy accessibility to all components and tubes.

In Figure 23 the 3-phase line voltage regulator is shown with its door open. This regulator provides voltage regulated at 115 plus or minus 0.5 volts regardless of line voltage variations from 100 to 130 volts, thus ensuring proper operation of the system under any conditions of primary power.

Figure 24 is a photograph of a full-scale wooden model of the Master Console Indicator used by our design engineers in arriving at a unit satisfactory to our customer and to ourselves. The PPI tube is located centrally with the picture controls conveniently grouped around the outside.

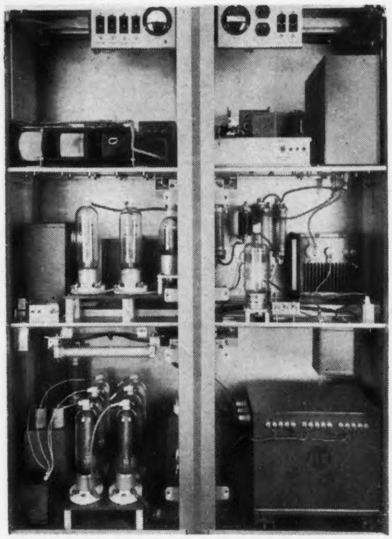


Figure 22

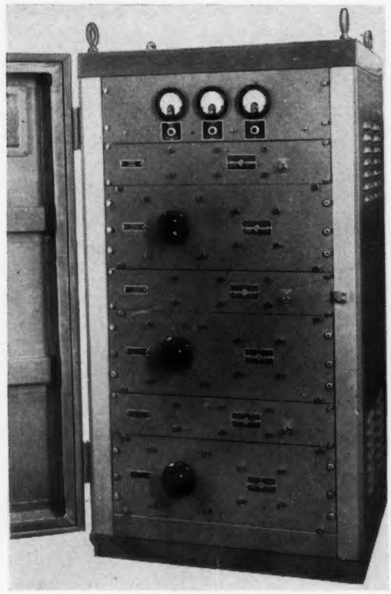


Figure 23

Figure 24

At the left hand of the operator are video mixing controls which permit adjustments of signal levels such as video map, beacon signals, MTI video, normal video and electronic cursor. Above these controls is a blank panel which, in the final models, will contain the radio-telephone controls used by the operator to communicate directly with the aircraft.

At the right hand, beneath a glassed-in door, are system remote controls and pilot lamps. The joystick to the right of the desk shelf permits the operator to locate a navigation cursor on the face of the PPI for rendering assistance to pilots aloft when necessary.

The product design of the console reflects the same design philosophy as the equipment described previously. All components can be serviced quickly and easily by opening doors which expose tubes and test points and, if necessary, pulling forward the chassis which swing out for easy access.

Performance Monitor

Earlier, in the discussions of the AASR, some emphasis was placed on the importance of the parameters of the radar equation and the desirability of preventing the performance of the system to be degraded by age and temperature. While much can be done to control both of these degrading influences by proper design, it is still important to ensure that those portions of the equipment which have a bearing on the system parameters be maintained at peak operating level at all times so that maximum performance of the system will prevail.

For this reason, integral test equipment has been included in the AASR to enable continuous monitoring of its performance without disturbing normal radar operation. The two important parameters, noise figure (F) and transmitter power (P), are continuously indicated. In addition, measurement of VSWR and crystal quality can be made readily. The noise-figure and transmitter-power indicators are capable of alerting the remote operator by visual means when the radar is operating outside of preset limits.

SITING AASR STATIONS

The selection of suitable AASR sites adjacent to airports has not been without its difficulties. Figure 25 is a simplified sketch showing the geometry of a typical airport. The heavy lines represent runways of about 8,000 ft in length. The circle has a radius of two miles and is centered on the airport control tower. The two-mile figure is the maximum distance which the equipment specification requires between the transmitter and the control tower. The lighter lines running parallel to the runways at a distance of one and one-half miles (the required radar minimum range) represent boundaries inside of which the radar antenna may not be located without resulting in blind spots at points along the runways or runway extensions. The shaded portion, then, represents the only area inside of which the antenna may be located without chance of blind spots and without exceeding the two-mile cable requirement.

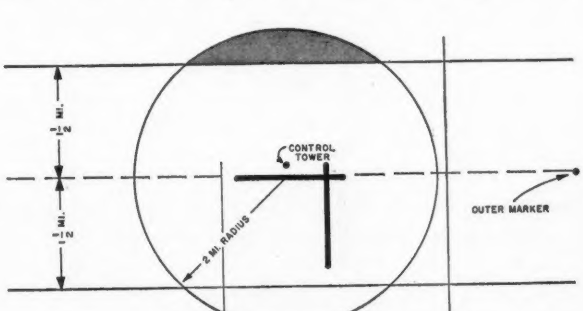


Figure 25

Typical geometry of airport and vicinity. Shaded area shows the only location suitable for radar antenna compatible with minimum range of 1½ miles and maximum control cable length of 2 miles.

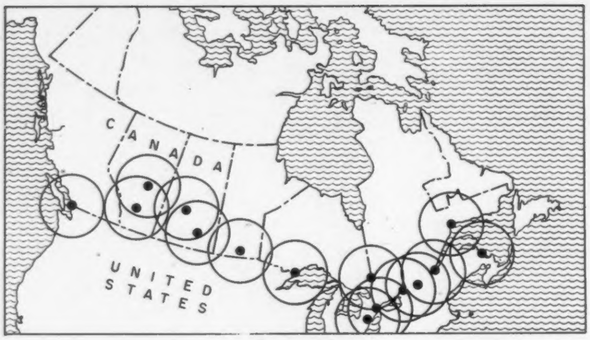


Figure 26
Map of Canada showing radar locations and coverage

Obviously, it is desirable that the radar "see" an aircraft as close to touchdown as possible. Unfortunately, it is not always feasible to place the antenna within the shaded area, e.g., when this happens to coincide with a valley deep enough to require an antenna tower of impractical height.

When it becomes impossible to select a suitable site within the limited space shown, there are two solutions to choose from. These are: (a) to move the antenna to a more distant location and use a long-range data transmission system such as microwave link or carrier coaxial cable, or (b) locate the AASR close to the airport at any convenient spot and employ a second radar of low transmitter power suitable for close-in viewing to ranges of a few hundred yards. The selection of alternatives is one of economics and conditions. At the Lakehead (Port Arthur, Ontario), for example, it will be necessary to locate the AASR antenna some eight miles from the airport in order to permit viewing towards Winnipeg across the high terrain lying to the west of the airport.

Problems of this sort remain to be solved in the field. For this reason, the AASR has been designed with flexibility so that data collected by the transmitter/receiver can be distributed to control points in many ways. With this and the basic concepts of performance, reliability, ease of maintenance and long life with continuous operation incorporated in the equipment, Canada will possess, upon completion of fifteen installations coast to coast (Figure 26), an enviable example to the world in her air traffic control service.

BIBLIOGRAPHY

(1) W. M. Hall – *Prediction of Pulse Radar Performance*, Proc. I.R.E., Vol. 44, No. 2, February 1956.

(2) L. V. Blake – *The Effective Number of Pulses per Beamwidth for a Scanning Radar*, Proc. I.R.E., Vol. 41, p 770, June 1953.

(3) P. C. Sandretto – *Elements of the Air Traffic Control Problem*, I.R.E. Transactions, Vol. ANE-2, No. 2, June 1955.

(4) L. N. Ridenour – *Radar System Engineering*, M.I.T. Radiation Laboratory Series, Vol. I, McGraw-Hill, 1947.

RCAF TEST AND DEVELOPMENT†

by S/L O. B. Philp*

Royal Canadian Air Force

INTRODUCTION

When I was asked to deliver a paper at this meeting, one of three papers to be delivered by test pilots, I immediately considered that a technical paper on some aspect of test flying was in order. However, as this was to be the first occasion that Canadian test pilots would have an opportunity to speak to these Institutes, as members of the newly-formed Test Pilots Section of the C.A.I., I thought that a general paper on RCAF Test and Development, its history, role, organization, test flying activities and its relationship with the Canadian aircraft industry, would be more appropriate.

HISTORICAL REVIEW

The first flying experiments carried out in Canadian military aviation were aerial photography tests from a balloon in 1883. It was 1907, however, before the Aerial Experiment Association was formed in Canada by Dr. Alexander Bell and two Canadians, Casey Baldwin and J. A. D. McCurdy, now the Honourable J. A. D. McCurdy. Canadian research, design and testing of aircraft really began with the forming of this association, but it was several years before the Canadian Air Force was established and became involved in the intriguing business of aeronautical test and development.

The RCAF unit responsible for test and development work is the Central Experimental and Proving Establishment. The history of this unit begins with the conception of the Canadian Air Force in 1920. At that time, the foundation of what is now CEPE was laid under the control of the Director of Technical Services for the Air Board, but it was 1931 before the unit was established as a permanent part of the RCAF. Through the years this unit has been known by various names, including Test and Development or more commonly as "Tiddle and Diddle". This name was changed, probably for obvious reasons, to Experimental and Proving and finally to Central Experimental and Proving, the name by which it is known today.

The growth of CEPE, from the time it was established as an RCAF unit in 1931 until after the Second World War, was for the most part static. Although test and development work was carried on through this period and records of the unit's achievements show that it was active, the unit did not really come into its own until after the war. Synonymous with the expansion of the RCAF and the growth of the Canadian aircraft industry, the necessity for a unit such as CEPE was more fully recognized and its activities and responsibilities were expanded accordingly.

THE ROLE OF CEPE IN THE RCAF

To appreciate the role of CEPE, the following are the general responsibilities of this unit given in broad terms:

(a) To evaluate and carry out performance and handling trials on aircraft designated for RCAF use.

(b) To evaluate, prove and, as applicable, design modifications to aircraft or associated aircraft equipment and accessories.

(c) To carry out acceptance flight tests on all RCAF aircraft after civilian manufacture or overhaul.

(d) To set and maintain the standards of flight test methods and procedures for the RCAF.

(e) To assess developments of interest to the RCAF.

(f) To provide experimental and research flying services for other governmental agencies.

THE ORGANIZATION OF CEPE

CEPE is under the functional and administrative control of Air Materiel Command, whose headquarters is in Ottawa, Ontario. The unit headquarters of CEPE and its main testing centre is at Rockcliffe, Ontario. As it is not possible to concentrate all the activities of CEPE in one geographic location, the unit maintains detachments which carry out specific test functions in various parts of Canada. The main detachments are:

(a) CEPE Climatic Detachment located near Edmonton, Alberta.

(b) CEPE Air Armament Evaluation Detachment located at Cold Lake, Alberta.

(c) CEPE detachments at the National Aeronautical Establishment and Defence Research Board establishments.

(d) CEPE detachments at Aircraft Manufacturers.

†Paper read at the I.A.S./C.A.I. International Meeting in Toronto on the 26th November, 1956.

*Formerly Chief Test Pilot, Central Experimental and Proving Establishment.

PERSONNEL

Any aeronautical organization, civilian or service, which is charged with the responsibility of carrying out flight test and development work, must, if it is to accomplish its aim, employ only the best trained and experienced personnel. This applies to design, flight test engineers and test pilots alike.

Assuming for the moment that the design engineers have carried out their job to perfection, let us consider the work of the flight test engineer and test pilot, who must prove the design. Every minute of flight testing on an aircraft, especially from the time the aircraft first flies until it is ready for operational or squadron service, is extremely valuable. In these days of complex aircraft, to obtain and analyze flight test results quickly and accurately requires the abilities of specialists in the flight testing field – the test pilots and flight test engineers are these specialists. The RCAF is fortunate in that it can generally select suitably qualified personnel, who have had considerable field experience, and train them for flight testing work. The personnel employed at CEPE are, in the main, highly qualified in their respective specialties whether it be engineering or flying.

TRAINING OF TEST PILOTS

The evolution of flight testing began over fifty years ago with the Wright Brothers, who designed, built and tested their own aircraft. The "do-it-yourself" attitude of the pioneers of flight soon gave way to the designing and manufacturing by engineers and the flight testing by someone else. This could imply, of course, that the designers had little faith in their product and a "fall guy", the test pilot, was hired to take the risk of proving the machines would fly. I expect that, even in the early days of flying, the need for a skilled pilot to test aircraft was recognized.

In the period between the first and second world wars, test flying in the service was done by any good pilot who happened to be available. The second world war soon proved that this system was no longer satisfactory because valuable testing time was being wasted while new pilots learned the fundamentals of flight testing. It became obvious that test flying was becoming a specialty and that service pilots, who were to be employed on flight testing duties, required formal training in this field. This problem was recognized by both the United States and England and test pilot schools were established in these countries.

The RCAF has fortunately been able to utilize these schools to train its test pilots. This method of training RCAF test pilots not only ensures that these pilots obtain a sound knowledge of the basic principles and fundamentals of test flying, but also enables each pilot trained to become familiar with the latest developments in either the United States or England, as the case may be. I would point out that a pilot graduating from a test pilot school does not know everything about test flying and probably never will and, depending upon his past experience, he requires a period of practical experience after his training before he can assume the responsibilities for a test flying project. However, from my own experiences and associations, I consider that the RCAF test pilots of CEPE are as well informed and capable as any in the business.

RCAF pilots, who wish to be employed on testing work, apply voluntarily for a test pilot's course. Because of the qualifications required, even the keenest candidates are between 27 and 29 years of age before they are eligible to apply. This generally ensures that the candidate is a dependable and mature individual, who, with the other necessary qualifications, should make a good test pilot. The test pilot's course supplies the final answer.

Although RCAF trained test pilots are highly qualified and capable, I do not think we will ever have one who would have the qualifications advertised for by an American company, which were: to possess an aeronautical engineering degree, have four thousand hours flying experience, be a graduate of a test pilot's school and be not more than twenty four years of age. What test organization couldn't use a few pilots with these qualifications?

In my estimation, the Canadian aircraft industry, which has many good pilots but few trained test pilots, will have a problem in the near future, in obtaining pilots with the desired qualifications. The Test Pilots Section of the C.A.I. recognizes this problem and there is little doubt that both the industry and the RCAF will be affected eventually if some means of supplying industry with qualified test pilots in the future is not found.

THE JOB OF THE RCAF TEST PILOT

Test flying is a serious and painstaking business. Sometimes there is an element of calculated risk, but any risk is kept to a minimum by exhaustive ground tests. Test pilots, however, must be temperamentally suited for this work. Any good fighter, bomber, transport or other type of pilot, even if specially trained, will not necessarily make a good test pilot unless he is temperamentally suited for the job. The Hollywood version of the white scarf over the shoulder type of test pilot, calmly carrying out hair-raising vertical dives with twelve "g" pullouts, before breakfast, does not exist in the RCAF or any other test organization that I know of.

On most flight test projects carried out by CEPE, a test pilot and flight test engineer unite to form a test team. CEPE's experience has shown that pairing up an engineer and test pilot ensures that the best test results are obtained. This system demands that each member of the test team has at least a basic understanding of the other's problems and brings engineers and pilots together at a working level. In the past, this intimate link did not exist and the engineers and flyers observed each others work with some skepticism.

The primary job of the test pilot is to search for and produce accurate facts – facts which the engineers can use to determine performance or substantiate theory and facts which can be used by air staffs to determine suitability and future requirements. There are occasions when it is not possible to collect data and produce facts. It is then the test pilot's second job to supply qualitative opinion – not personal opinion, but educated, intelligent opinion which can be presented and substantiated.

There is a third function that RCAF test pilots must be able to perform and that is the function of a lawyer, so that he can interpret test specifications. I think that

RCAF test pilots are required to use their "legal ability" more than any other service because the RCAF not only uses British and American aircraft, built under licence in this country, but also Canadian designed and built aircraft. Each of these aircraft is tested to a different specification, which is disturbing enough, but when we take a British or Canadian engine and install it in an American airframe, or build a British aeroplane to British specifications and then test it to American specifications, the lawyer test pilot is really needed. It is assumed by many in the aeronautical field, both civilian and service, that these specifications are basically the same, but they vary considerably in specific tests and these differences our test pilots must be aware of. I think there is a real need for a standard flight test specification applicable to all types of military aircraft. It may be that the manuals of the Advisory Group for Aeronautical Research and Development are a step in this direction.

TEST FLYING ACTIVITIES

The RCAF, like any other air force, is dependent upon the capabilities of its aircraft to carry out their assigned role. CEPE is one of the Air Force's instruments which ensures that its aircraft not only meet design specifications, but also provides information on the complete capabilities of aircraft and associated equipment.

To ensure that a new aircraft meets the required specifications and is airworthy, the RCAF has adopted a similar evaluation and test program to the one used by the USAF. This program is broken down into phases, with the aircraft manufacturers being responsible for some phases and the RCAF, through CEPE and its Climatic and Air Armament Evaluation Detachments, responsible for others. As yet, the RCAF has had little experience with this new system, but it is hoped that past mistakes made during the development period on new aircraft will not be repeated during the development testing on the CF-105 and CL-28.

In addition to this function, there are many other test and development projects carried out by CEPE on aircraft and aircraft equipment. These range from the testing of photographic and navigational equipment to the evaluation of automatic parachute devices and even rain repellants. There are also many special investigations into air matters to supply the technical and air staffs with information pertinent to future requirements.

To ensure that all aircraft produced for the RCAF continue to meet the prescribed specifications, acceptance flight tests on each and every aircraft are carried out by CEPE at the manufacturers, before the aircraft is delivered to the user unit. This aircraft acceptance testing by the service is as old as industry itself and at one time was done by any pilot who was available. However, as aircraft became more complicated, it was evident that there was a lack of consistency among pilots doing acceptance testing and it was obvious that it would be necessary to train aircrews specifically for acceptance test duties and employ them solely on this work. In the beginning, this sudden change was not exactly met by the manufacturer with open arms. Being good business men, their primary purpose was to deliver a satisfactory aircraft or piece of equipment to the RCAF by a certain date. However, it soon became evident that "satisfactory" to a manufacturer and to the acceptance test crew had two different meanings. Both the manufacturer and service test crew had a great deal to learn and many hurried telephone calls emanated from the offices of production chiefs at the various firms to Air Materiel Command or Air Force Headquarters asking what authority some Flying Officer Prune had to reject his beautiful product. Fortunately, most of this trouble was short lived and, although there are still some difficulties in this business, generally in the interpretation of specifications and whether or not an item meets the specification, there is no doubt that the RCAF is receiving an infinitely better product. The aim of acceptance flight testing is to ensure that aircraft will meet their prescribed specifications and thus be able to carry out their operational role; therefore, acceptance standards must be high.

It is essential that military aircraft be able to operate in extreme climatic conditions and Canada has these extremes. The testing of aircraft to determine their suitability to operate under these extremes, and especially in winter conditions, is the job of CEPE's Climatic Detachment. This detachment conducts experiments and tests under Canadian climatic conditions and assists in the design and development of modifications required as a result of these tests. These tests encompass the whole aircraft and its systems to determine if there are any limitations to its operational ability due to climatic conditions.

An operational military aircraft, no matter how well it can fly and operate under all climatic conditions, is of little use to the RCAF unless it is effective as a weapon. CEPE's Air Armament Evaluation Detachment provides the facilities which ensure that RCAF armament equipment and systems meet specifications and are capable of fulfilling military requirements.

In addition to these activities, CEPE provides research flying services for the National Aeronautical Establishment and various Defence Research Board Establishments.

Throughout its testing activities, CEPE is continually searching for factors which are detrimental to flight safety and airworthiness. Flight safety is an important matter to the RCAF. The cost of aircraft accidents runs into the millions of dollars each year. Many of these accidents are caused by pilot error, material failure or maintenance errors. There have been many accidents, however, where the basic cause was design. The complexity of the design in a new aircraft and the aircraft's major components and systems is appreciated and it is not suggested that the engineers do not attempt to remove all possible factors which could contribute to an accident. Neither is it suggested that there should be a safety device for a safety device or an emergency system for an emergency system. The penalty that is being paid for the necessary flight safety features, especially on high performance aircraft, is already severe. There is, however, one factor that is repeatedly overlooked. This was summed up by the RCAF Director of Flight Safety when he said, "It is paramount in the interest of flight safety that once errors have been revealed and a fix established they should never be permitted to reappear again in a later design of any type

of aircraft." Unfortunately many of these design faults keep reappearing. Test pilots must accept new designs in aircraft and types of systems for this is a mark of progress, but the reappearance of poor design features, especially in cockpit controls, is not progress. Fuel selection controls which can be confusing in operation still reappear, as do feathering switches positioned beside fire extinguishing switches or oil shut off switches, all the same design and colour. Warning lights positioned behind the pilot's forward view, especially in jet aircraft, are common and the positioning of circuit breakers in the cockpit, so that when the pilot is strapped in he cannot possibly reach them, seems to have been a designer's delight. In this day of artificial control systems, it is hoped that the emergency systems operating from the main hydraulic or electrical system is past history. The nose wheel steering device, which ceases to work momentarily when the flaps are pulled up after landing, should also be a memory. Testing a new aircraft or piece of equipment with previously proven faults incorporated does not indicate improvement and our operational aircraft must be improved continually.

In all these test activities, which are technical in nature, the test pilot not only provides the important and vital link with the engineering and research people, but also provides the necessary link with the operators. In this day of ever-changing requirements and rapid development in military aircraft, the role of the test pilot has never been more important and he can no longer be regarded by the technical minded as just a "drivers, airframe". At CEPE the test pilot and flight test engineer are partners in this business of "learning to test and testing to learn".

CEPE AND THE CANADIAN AIRCRAFT INDUSTRY

It is apparent from the foregoing that CEPE, as the test and development representatives of the RCAF, maintains a close relationship with the experimental and test flying departments of the various aircraft manufacturers who design and produce aircraft for the service.

This relationship has not always been congenial and, even now, there are areas in this common field where there are many disagreements over such things as specifications, test procedures and end results of tests. These disagreements are acceptable when constructive criticism and discussion, supported by facts, result in progress. They are not acceptable when they result in extensive delays to RCAF programs. The RCAF, as the buying customer, has the automatic right to criticize the product they receive. I have heard senior members of the various companies' development staffs complain that CEPE would never be satisfied with anything. This generalization is right, for to be completely satisfied would end progress and CEPE must criticize, within reason, on behalf of the RCAF in testing matters.

CEPE and the flight test organizations of industry have many problems in common. The numerous test specifications and procedures, referred to earlier, are one. The testing of aircraft out of aerodromes, situated within heavy commercial traffic and near built-up areas, is another. Test pilots are being plagued with new air regulations which are making it increasingly difficult to carry out some test flights. This, coupled with our changing weather conditions, causes frustrating delays in completing programs.

The exchange of information between Canadian test pilots, service and civilian, in matters which concern this profession only, has been long overdue. There are less than one hundred pilots in Canada employed in the testing field and this includes research, development and production flying. Up until last spring, many of these test pilots did not know one another or even the type of aircraft work their respective companies were engaged in. I think it is absolutely necessary that, within the bounds of security, the service and civilian test pilots of Canada should be able to exchange information and have a means of contributing jointly to the solving of common problems. The Test Pilots Section of the C.A.I. should achieve this purpose.

THE NUMERICAL DETERMINATION OF TRANSIENT TEMPERATURES IN WINGS†

by E. Kosko*

Avro Aircraft Limited

SUMMARY

The laws of one-dimensional transient heat conduction are reviewed, beginning in their exact differential formulation. Convective heat transfer along the path of the main heat flow is also considered. As an alternative to the laborious analytical method, a formulation in terms of finite differences is presented. This yields numerical solutions which can easily be calculated to any desired accuracy. The practical application of the method is demonstrated in a series of examples, such as may be encountered in the investigations of heating of high-speed aircraft wings.

INTRODUCTION

THE temperatures due to aerodynamic heating or cooling of supersonic aircraft must be known with a fair degree of accuracy in order to evaluate their effects on the airworthiness of the structure. The two quantities which govern the inner temperature history and distribution are the boundary layer temperature and the heat transfer coefficient. Both depend on a large variety of factors and their determination, either by theory or by experiment, is not a simple matter. In this paper, the point of view of the structural analyst is adopted and these two quantities are assumed to be given functions of time and of position on the surface of the aircraft.

Within the boundary conditions thus specified, the calculation of the temperature distribution in a solid body amounts, in the general case, to solving a partial differential equation with the space coordinates and time as independent variables. In aircraft structures of the thin-wall type, one space coordinate is usually sufficient to describe the position of a point in a cross section; this coordinate may be taken as a distance along the skin middle line or along a web. It has been demonstrated that spanwise variations of temperature are relatively unimportant and are not likely to produce any appreciable thermal stresses.[1] We shall therefore restrict our considerations to one-dimensional heat flow.

In all but the simplest cases, the analytical solution is very laborious if practical at all. Fortunately, approximate solutions based on a finite-difference approach are relatively easy to obtain. An outline of the method is given in this paper, together with applications to some examples for which alternative analytical solutions were also available.

Before presenting the finite-difference method, a short survey of the classical formulation in terms of a partial differential equation is given. The establishment of a heat balance is shown to be the common feature of both methods. On this purely physical basis it should not be difficult to derive formulae applicable to any new cases. Particular attention is given to conditions which involve convective heat transfer.

It appears that the accuracy of the finite-difference method is much better than the accuracy of the data; in particular, that of the heat transfer coefficients. Many of the computations do not even require a desk calculator, slide-rule accuracy being sufficient for the purpose. On the other hand, when more elaborate results are desired and a digital computer is available, the simple formulae of the text lend themselves to easy programming.

The finite-difference method has for some time been a standard tool in industrial heat flow calculations[2, 3, 4]. For some reason, however, in the literature concerned with the aerodynamic heating of wings, the analytical methods of solution are predominant[5, 6, 7, 8]. As a result, many engineers not specialized in this type of work feel unable to determine, even roughly, temperature distributions in structural members. The present paper aims at correcting this situation.

SYMBOLS

d	thickness, ft or in
H	height or depth, ft or in
L	length, ft or in
x	space coordinate, ft or in
A	cross-sectional area, ft²
V	volume, ft³
t	time, hr or sec
T	temperature, °F
Q	quantity of heat, Btu

†Received 14th July, 1955, in the form of Avro Stress Report GEN/1090/3. This paper is an abridged version, received 22nd August, 1956.

*Assistant Chief Stress Engineer.

q	heat flow per unit area and hour, Btu/(ft²hr)
ρ	density of solid, lb/ft³
C	heat capacity of body, Btu/°F
c	specific heat of solid, Btu/(lb °F)
k	thermal conductivity of solid, Btu/(hr ft °F)
h	coefficient of surface heat transfer, Btu/(hr ft² °F)
$\kappa = k/\rho c$	thermal diffusivity, ft²/hr or in²/sec
$\beta = h/\rho cd$	convective time constant, hr^{-1} or sec^{-1} for thin body
$r = \kappa\Delta t/(\Delta x)^2$	modulus in finite-difference procedure for conduction (inverse of Dusinberre's M)
$s = h\Delta x/k$	modulus for convection (Dusinberre's N)

Subscripts

First subscript refers to the space coordinate, second subscript refers to time, e.g. T_{ij} represents temperature at point i (coordinate x_i) at a time point j (time t_j). The time subscript is sometimes dropped.

A	ambient
B	body
S	skin or surface

DIFFERENTIAL FORMULATION OF ONE-DIMENSIONAL UNSTEADY HEAT FLOW

The mathematical treatment of transient heat conduction problems in solid bodies is based on three physical laws which may be stated as follows[3, 4].

The *law of heat storage* is expressed by the relation

$$\Delta T = \Delta Q/C \tag{1}$$

where C is the thermal capacity of a region whose temperature is increased by ΔT due to the net heat gain of ΔQ. The specific heat is given by

$$c = C/W \tag{2}$$

where W is the weight of the portion considered.

When referred to a unit length of time, this same law shows the rate of temperature rise as being proportional to the rate of heat input.

The *law of heat conduction* due to Fourier is usually written as

$$Q = k\,(T_1 - T_2)\,tA/L \tag{3}$$

or

$$q = -\,k\partial T/\partial x \tag{4}$$

and states that the rate of heat transfer by conduction per unit cross-sectional area is proportional to the negative temperature gradient. The thermal conductivity k is a property of the material and is usually taken as a constant.

The two laws just stated can be combined into the Fourier-Poisson equation

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial x^2} \tag{5}$$

in which $\kappa = k/(c\rho)$ is the thermal diffusivity of the material.

Newton's law of heat transfer through a surface states that the amount of heat transferred from an ambient fluid to a solid body is proportional to the negative drop in temperature, to the area of the wetted surface, and to time. With T_A denoting the ambient temperature, and T_B the body surface temperature, the relation may be written

$$Q = h\,(T_A - T_B)\,At$$

or, in terms of a time rate of heat flow per unit area,

$$q = \frac{1}{A}\frac{dQ}{dt} = h\,(T_A - T_B) \tag{6}$$

In contrast to the constant k, the surface or film coefficient h is a complicated function of fluid velocity, of the condition of the boundary layer etc. The large variations which are possible in the magnitude of h do not seem to warrant too much accuracy in calculations of conductive heat flow when convection is also present.

The rate of heat flow represented by Eq. (6) may be equated to the rate conducted into the body, given by Eq. (4); the boundary condition for convective heat transfer is thus obtained,

$$-k\partial T_B/\partial x = h\,(T_A - T_B) \tag{7}$$

The same relations, Eqs. (6) and (7), may also be applied to heat transfer through a contact surface between two solid bodies, when an appropriate value of h is used.

Some special cases of heat transfer

If the main direction of conductive heat transfer is along a thin body (rod or web), which on its lateral surface is in contact with an ambient fluid, there will be a secondary transfer between the body at the local temperature T and the fluid at T_A. Assuming the temperature to be uniform over a cross section A of the body, the rate of this secondary flow for a length element dx is

$$(dQ/dt)_s = h\,(T_A - T)\,b\,dx \tag{8}$$

where b denotes the wetted perimeter of the cross section being in contact with the fluid.

(a) When there is no conduction along the body, due to its temperature being uniform (e.g. when a thin body is completely immersed in the fluid), all the heat gained from the fluid is stored in the body,

$$\left(\frac{dQ}{dt}\right)_s = c\rho A\,\frac{dT}{dt}\,dx$$

Equating this expression with the preceding one, we obtain

$$dT/dt = \beta\,(T_A - T) \tag{9}$$

where $\beta = hb/(c\rho A)$ is a time constant having the dimension (hr^{-1}). If the ambient temperature remains constant during the process, and if T_i is the initial temperature of the body at time $t = 0$, Eq. (9) yields the integral

$$T - T_A = (T_i - T_A)\,e^{-\beta t} \tag{10}$$

For a variable ambient temperature, a step-by-step solution of Eq. (9) is always possible.

(b) In the case of temperature gradients in the x direction, the heat balance for an element dx is obtained by combining Eqs. (5) and (9),

$$\frac{\partial T}{\partial t} = \kappa\frac{\partial^2 T}{\partial x^2} + \beta\,(T_A - T) \tag{11}$$

FINITE-DIFFERENCE FORMULATION OF ONE-DIMENSIONAL UNSTEADY HEAT FLOW

The finite-difference relations are best derived by considering the body as consisting of a number of small but finite regions and establishing conditions of heat balance between these regions, using average values for the temperature and for the thermal properties of each region. The length of the body is subdivided into n equal intervals, each of length Δx. Each region is represented by a control point, denoted by a subscript i which varies from 0 to n.

The time variation of the temperature is also considered at a discrete number of time points, beginning at an origin $t = 0$. Successive time points, separated by a constant time interval Δt, are denoted by the subscript j.

Thus, at a point i distant $i\Delta x$ from the origin, and at a time $t = j\Delta t$, the temperature is denoted by T_{ij}. When only one subscript is used, it refers to the space coordinate.

Heat conduction within the body

A heat balance is established for region i in the time interval from j to $j + 1$. For a unit cross-sectional area the heat capacity of the region is $c\rho\Delta x$. In the time interval Δt, the amount of heat received from region $i - 1$ is $k\Delta t(T_{i-1} - T_i)/\Delta x$. The amount lost to region $i + 1$ is $k\Delta t(T_i - T_{i+1})/\Delta x$. The amount stored in region i is $c\rho\Delta x(T_i' - T_i)$. Note that T_i, T_{i-1} and T_{i+1} stand for T_{ij}, $T_{i-1,j}$ and $T_{i+1,j}$ respectively, and T_i' stands for $T_{i,j+1}$.

The balance of these quantities of heat yields a relation

$$k\Delta t\,(T_{i-1} - T_i)/\Delta x - k\Delta t\,(T_i - T_{i+1})/\Delta x = c\rho\Delta x\,(T_i' - T_i)$$

between the "prior" temperatures at point i and at its neighbouring points on both sides, and the temperature T_i' at the point in question at the next moment $j + 1$. Solving for the unknown T_i', we have

$$T_i' = T_i\,(1-2r) + (T_{i-1} + T_{i+1})r \tag{12}$$

where

$$r = \frac{k\Delta t}{c\rho\,(\Delta x)^2} = \kappa\Delta t/(\Delta x)^2 \tag{13}$$

The ratio r (this is the reciprocal of Dusinberre's M) can be chosen within certain narrow limits. It must be positive, but such that the coefficient of T_i is positive also, i.e. $r \leq \frac{1}{2}$. Otherwise, the finite-difference procedure either diverges or exhibits instability. Thus, for a given value of the space interval Δx, the time interval cannot be chosen quite freely; in particular, it cannot exceed the value $(\Delta x)^2/2\kappa$.

A particularly simple relation corresponds to the value $r = \frac{1}{2}$,

$$T_i' = \tfrac{1}{2}\,(T_{i-1} + T_{i+1}) \tag{14}$$

This is the counterpart of Schmidt's averaging graphical procedure. Other values of r resulting in simple averages are $\frac{1}{3}$ and $\frac{1}{4}$. It has been proved that the error of the finite-difference calculation is a minimum for $r = \frac{1}{6}$, leading to the equation

$$T_i' = \tfrac{2}{3}\,T_i + \tfrac{1}{6}\,(T_{i-1} + T_{i+1}) \tag{15}$$

Eq. (12) and similar ones derived from it, either by specialization or by extension to particular conditions (as is done in the following sections), are used at every step in the numerical work. For convenience they are sometimes laid out in the form of a "computational molecule"

$$\left.\begin{array}{l} \boxed{T_{i-1}} \times r \\ \boxed{T_i} \times (1-2r) \\ \boxed{T_{i+1}} \times r \end{array}\right\rangle = T_i' \qquad \text{or} \qquad \left.\begin{array}{c} \boxed{r} \\ + \\ \boxed{1-2r} \\ + \\ \boxed{r} \end{array}\right\} = 1$$

The "molecule" shows in a graphical way the connection between the various temperatures involved. The layout of the tabular work follows the same pattern, i.e. every line in the table represents a point in space, and every column represents a time point.

Heat transfer at a boundary

Three cases will be considered in which the prescribed ambient temperature may be either constant or variable with time.

(a) *Prescribed surface temperature.* A control point, say 0, is taken right at the surface and its temperature is directly entered into the table for the successive time points. The temperature at the neighbouring point, $i = 1$, can be determined from the previous temperatures T_0, T_1 and T_2 by means of Eq. (12) or its variants. Thus, the scheme of the preceding section is directly applicable to this case.

(b) *Adiabatic surface.* No heat passes through such a surface, i.e. the temperature gradient vanishes there, $(\partial T/\partial x)_S = 0$; this condition also prevails at the centre line of a slab symmetrically heated from both sides. In other words, if the temperature distribution is extended beyond control point m, which represents the adiabatic surface, we must have $T_{m+1} = T_{m-1}$. Substituting this relation into the general Eq. (12) for point m, we obtain

$$T_m' = T_m\,(1-2r) + T_{m-1}\,2r \tag{16}$$

(c) *Convective heat transfer through surface.* Again let a control point 0 be located at the surface which is in contact with a medium having the ambient temperature T_A. A surface transfer coefficient h is assumed to be given; this may be either constant or variable with time. A balance of heat is established for the region comprised between the surface and the next control point, $i = 1$. The body (or rather the temperature distribution curve) is fictitiously extended beyond the surface and a control point $i = -1$ is placed at a distance $-\Delta x$ from point 0. The temperature gradient at the boundary is then represented by $(T_{-1} - T_1)/2\Delta x$, and the convective condition is written

$$k\,(T_{-1} - T_1)/2\Delta x = h\,(T_A - T_0)$$

This is combined with Eq. (12) for point 0,

$$T_0' = T_0\,(1-2r) + (T_{-1} + T_1)\,r$$

which permits the elimination of the fictitious temperature T_{-1},

$$T_0' = T_0\,[1-(1+s)\,2r] + T_1\,2r + T_A\,2rs \tag{17}$$

The non-dimensional quantity

$$s = h\Delta x/k \tag{18}$$

is analogous to Biot's convective modulus and is identical with Dusinberre's N.

When the coefficient s is large, the factor T_0 in Eq. (18) may become negative unless a very small time interval is chosen. In order to avoid this alternative, which would require a laborious computation, another formula, suggested in Reference 2, may be applied, viz.

$$T_0 = (T_1 + s\,T_A)/(s+1) \qquad (19)$$

where all three temperatures are taken at the same time point.

Convective heat transfer transversely to the main flow of heat

The main heat flow is assumed to take place in the direction x through a thin cross section A which has a wetted perimeter b. A secondary convective heat transfer is effected through the lateral surface between the medium at the ambient temperature T_A and the body at the local temperature T_i, the transfer coefficient being h. In the heat balance equation, this secondary transfer is represented by an additional term $hb\Delta x(T_A - T_i)\Delta t$. After simplification, the finite-difference relation becomes

$$T_i' = T_i(1-2r-\beta\Delta t) + (T_{i-1} + T_{i+1})\,r + T_A\beta\Delta t \qquad (20)$$

the symbols r and β having their previous meaning.

In a limiting case, when the conductivity of the body is so large that gradients in the main direction can be neglected (as is often the case for a thin skin), we may put

$$T_i = T_{i-1} = T_{i+1} = T$$

and find

$$T' = T(1-\beta\Delta t) + T_A\beta\Delta t$$

Comparing this expression with the exact solution given by Eq. (10), we see that for more accurate results, we should substitute $e^{-\beta\Delta t}$ for $(1-\beta\Delta t)$. Eq. (20) is then replaced by an improved formula

$$T_i' = T_i(e^{-\beta\Delta t} - 2r) + (T_{i-1} + T_{i+1})\,r + T_A(1-e^{-\beta\Delta t}) \qquad (21)$$

In either of these, the constants must be so chosen as to yield a positive coefficient of T_i.

Stepwise change in cross section of conducting body

Let the body have a width d_1 up to a control point m and a different width d_2 beyond it. The flow of heat just before the joint is proportional to $d_1(\partial T/\partial x)_{m-}$ and must be equal to the flow of heat beyond the joint $d_2(\partial T/\partial x)_{m+}$, i.e.

$$d_1(\partial T/\partial x)_{m-} = d_2(\partial T/\partial x)_{m+} \qquad (22)$$

The equivalent in finite-difference notation is found by establishing a heat balance for the region centered around m, whose volume is $V = \frac{1}{2}(d_1 + d_2)\,\Delta x\,1$. Heat received from $m-1$ is $kd_1\Delta t(T_{m-1} - T_m)/\Delta x$; heat lost to $m+1$ is $kd_2\Delta t(T_{m+1} - T_m)/\Delta x$; heat stored in region is $c\rho V(T_m' - T_m)$. After simplification, the balance of these quantities yields the relation

$$T_m' = T_m(1-2r) + T_{m-1}\,r\delta_1 + T_{m+1}\,r\delta_2 \qquad (23)$$

in which

$$\delta_1 = 2d_1/(d_1+d_2), \qquad \delta_2 = 2d_2/(d_1+d_2) \qquad (24)$$

A simpler but less accurate formula is used sometimes

$$T_m = \tfrac{1}{2}\,\delta_1\,T_{m-1} + \tfrac{1}{2}\,\delta_2\,T_{m+1} \qquad (25)$$

This is obtained by neglecting the heat capacity of the region around the joint.

Unequal intervals

If some discontinuity occurs at a point m, such that the two portions of the body cannot be subdivided into intervals of equal length, the necessity arises to work either with different intervals Δx_1 in one part and Δx_2 in the other, or to keep the same basic interval Δx all over and have a few intervals of modified length $\Delta x'$ on one or both sides of the discontinuity. A derivation similar to that of the preceding section results in the relation

$$T_m' = T_m(1-2\sqrt{r_1 r_2}) + T_{m-1}\,r_1\,\xi_1 + T_{m+1}\,r_2\,\xi_2 \qquad (26)$$

where

$$r_1 = \kappa\Delta t/(\Delta x_1)^2, \qquad r_2 = \kappa\Delta t/(\Delta x_2)^2,$$
$$\xi_1 = 2\Delta x_1/(\Delta x_1 + \Delta x_2), \qquad \xi_2 = 2\Delta x_2/(\Delta x_1 + \Delta x_2) \qquad (27)$$

NUMERICAL APPLICATIONS

In order to show the manner in which to apply the formulae of the preceding sections, a number of relatively simple problems will be treated. The problems have been so chosen that analytical solutions are available for comparison.

Semi-infinite slab with sudden temperature change at the surface

This is a classical problem in heat conduction; it also applies to a perfectly insulated long rod or web. Assume the initial temperature to be $T = 0$ up to a time $t = 0$ for all positive values of x, and the boundary point at $x = 0$ suddenly brought to a temperature $T = 1$. For best results, at time $t = 0$, the temperature at the boundary should be taken as the mean of $T = 0$ and $T = 1$, i.e. $T = 0.5$. The diffusivity of the material is taken as $\kappa = 1$; any other value of κ can be accounted for by adjusting the time interval Δt so as to give the same $\kappa\Delta t$.

The calculations have been performed for three different values of the modulus, $r = \frac{1}{2}$, $\frac{1}{3}$ and $\frac{1}{6}$, and for a sufficient number of points in time and space. Table 1 compares these results with the analytical solution for three time points. Due to lack of space, it

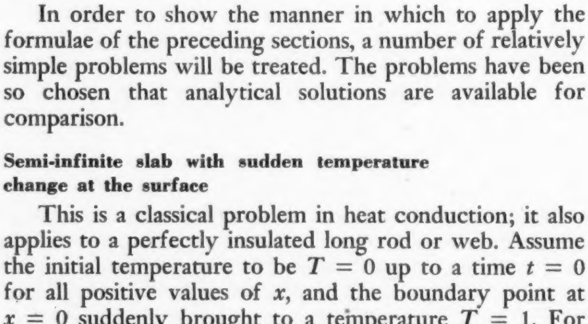


Figure 1

Semi-infinite slab—effect of a sudden temperature change at its surface

--------------- approximate solution ($r = \frac{1}{3}$)
———— analytical solution

Table 1
Semi-infinite slab. Sudden temperature change at face

Distance from face x, in	Elapsed heating time, sec 0	1.0 (a)	1.0 (b)	1.0 (c)	1.0 (d)	2.0 (a)	2.0 (b)	2.0 (c)	2.0 (d)	4.0 (a)	4.0 (b)	4.0 (d)
0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1	0	0.5	0.482	0.480	0.480	0.625	0.619	0.618	0.617	0.726	0.725	0.724
2	0	0.125	0.148	0.160	0.157	0.312	0.317	0.318	0.317	0.480	0.481	0.480
3	0	0	0.018	0.035	0.034	0.125	0.128	0.135	0.134	0.289	0.289	0.289
4	0	0	0	0.005	0.005	0.031	0.038	0.046	0.046	0.152	0.155	0.157
5	0	0	0	0	0	0	0.008	0.013	0.012	0.070	0.073	0.077

(a) $\Delta t = 0.5$ sec ($r = 1/2$); (b) $\Delta t = 0.333$ sec ($r = 1/3$); (c) $\Delta t = 0.167$ sec ($r = 1/6$); (d) Analytical solution.

is not possible to reproduce here the complete tabulation which was done to 3 decimals.

Figure 1 presents a plot of these solutions. It is seen that for values of time larger than $\sim \frac{1}{6}\, x^2/\kappa$ the agreement is satisfactory.

Slab of finite thickness with heat transferred at both faces by convection from a medium at constant temperature

A wide 2 in thick slab having a thermal diffusivity $\kappa = 1$ in^2/hr and a thermal conductivity $k = 1$ Btu/(hr ft °F) is at an initial temperature $T = 0$. At a time $t = 0$, it is plunged into a medium which is at a constant temperature $T_A = 814$°F. The coefficient of surface heat transfer is $h = 4.44$ Btu/(hr ft^2 °F). The varying temperature distribution over the thickness is to be determined for the period of initial heating. (Example taken from Reference 9.)

Assume $\Delta x = \frac{1}{8}$ in, $r = \frac{1}{4}$,

$$\text{hence } \Delta t = \frac{(1/8)^2}{4} = 1/256 \text{ hr and}$$

$$s = h\,\Delta x/k = \frac{4.44}{1.0} \times \frac{1}{8} = 0.555.$$

Within the slab, Eq. (12) with the above r becomes

$$T_i' = T_i \tfrac{1}{2} + (T_{i-1} + T_{i+1}) \tfrac{1}{4}. \qquad (i = 1, 2, \ldots, 7)$$

At the centre line ($i = 8$), the condition of symmetry represented by Eq. (16) becomes

$$T_8' = \tfrac{1}{2}(T_7 + T_8)$$

At the convective boundary ($i = 0$), Eq. (17) applies,

$$T_0' = T_0 \times 0.2225 + T_1 \times 0.5 + T_A \times 0.2775$$

The calculation has been carried out for the first 21 time intervals, with results plotted in Figure 2. Some of the numerical values are listed in Table 2, together with the analytical solution for the surface temperature.

The agreement is very satisfactory, except for the first four time points. The results of the numerical analysis are generally on the low side, which is probably due to the assumption of $T_A = 407$°F at time $t = 0$.

Temperature distribution in a wing spar web

The numerical example treated here is the same as that solved in Reference 5 by analytical methods. The wing skin is assumed to be a perfect conductor, i.e. its temperature will vary with time only, but not with position along the chord. No thermal resistance is assumed to exist between the skin and the spar cap so that

Table 2
Slab with convective heat transfer from a medium at constant temperature $T_A = 814$°F.

Temperature at point	Elapsed heating time, sec 0	56.25	112.5	168.8	225	281.3	168.8[(a)]
Ambient T_A	407	814	814	814	814	814	814
Face T_S	0	330.0	411.5	458	489	513	458
1/4 in	0	22.6	92.1	149.4	192	230	156
1/2 in	0	0	7.8	28.1	50.5	75.5	32
3/4 in	0	0	0.1	2.3	8.4	17.7	3.0
1.0 in (CL)	0	0	0	0.1	1.6	5.4	0
Face[(a)] T_S	0	336	413	458	489	513	

(a) Column and row represent analytical solution.

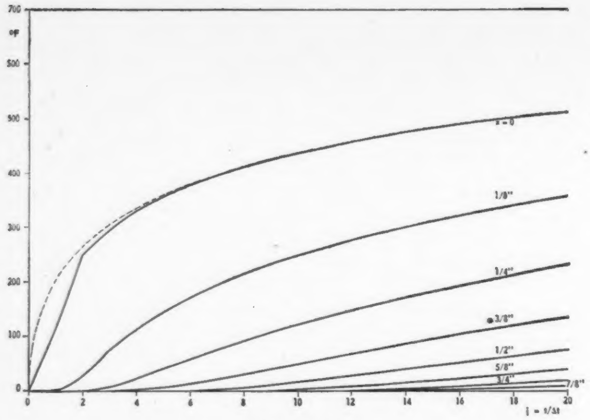


Figure 2
Slab with heat transferred at both faces by convection from a medium at $T_A = 814°F$
———— numerical solution
.... analytical solution

the web temperature at the joint with the skin is the same as the skin temperature.

The data of the problem are as follows (Figure 3):

Dimensions: $a = 12$ in $= 1.0$ ft, $b = 4.5$ in $= 0.375$ ft, $d_1 = 0.375$ in $= 0.03125$ ft, $d_2 = 0.1$ in

Material of skin and web: steel ($c = 0.1406$ Btu/(lb °F), $\rho = 489.6$ lb/ft^3, $k = 26.0$ Btu/(hr ft °F), $\kappa = 0.0186$ in^2/sec)

Heat transfer coefficient between boundary layer and skin, $h = 90$ Btu/(hr ft^2 °F)

Convective time constant for skin $\beta = 41.84$ hr^{-1} $= 0.01162$ sec^{-1}

Initial temperature $T_1 = 60°F$

Boundary layer temperature assumed as a step function of time, $T_A = 600°F$ for $t \geq 0$ (corresponds to a missile accelerating suddenly to $M = 3.1$ at 50,000 ft).

Radiation effects and convection inside the wing are neglected.

Under the above assumptions, the uniform skin temperature can be calculated by means of Eq. (10), as was done in Reference 5. The values of βt, $e^{-\beta t}$, $T_A - T_S$,

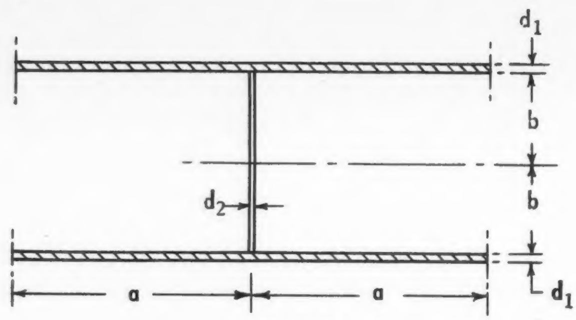


Figure 3
Dimensions of web and skin panels

T_S are entered as functions of time in the first rows of Table 3. The temperature at both ends of the web being known, we proceed to calculate the temperature distribution over the web by means of the numerical procedure.

Assume a space interval $\Delta x = 1.5$ in and a convective modulus $r = 1/6$, hence a time interval $\Delta t = \dfrac{1}{6}\,\dfrac{(1.5)^2}{0.0186}$ $= 20.17$ sec. Eq. (15) will be used for all the inside points of the web, except the point on the centre line where Eq. (16) applies. In this case the latter reads

$$T_{CL}' = T_{CL}\,\tfrac{2}{3} + T_2\,\tfrac{1}{3}$$

Table 3 summarizes the results for several time points. The temperature drop within the structure $T_S - T_{CL}$ has also been calculated; this quantity is indicative of the thermal stress in the spar web. It is seen to attain a maximum about 200 sec after beginning of heating.

Figure 4 shows the variation with time of the temperature of the skin and at the control points in the web. Figure 5 is a cross plot of the same data and shows the temperature distribution in the web for various values of the time parameter. These curves agree quite closely with those given in Reference 5.

Temperature distribution in wing skin and web

The preceding example is extended here to include the effect of finite conductivity in the skin. The same case has been treated, by a rather complicated analytical

Table 3
Temperature distribution in spar web $T_A = \text{const} = 600°F$

	Elapsed heating time, sec							
t	0	20.17	40.33	60.5	121.0	181.5	242.0	302.5
$e^{-\beta t}$	1.000	0.791	0.625	0.494	0.244	0.121	0.060	0.030
$T_A - T_S$	540	428	338	267	132	65	32	16
Temp. at $x=0$ (T_S)	60	172	262	333	468	535	568	584
1.5 in	60	60	78.7	106	198	273	330	373
3.0 in	60	60	60	63	91	136	185	234
4.5 (CL)	60	60	60	60	69	97	139	186
$T_S - T_{CL}$	0	112	202	273	399	438	429	398

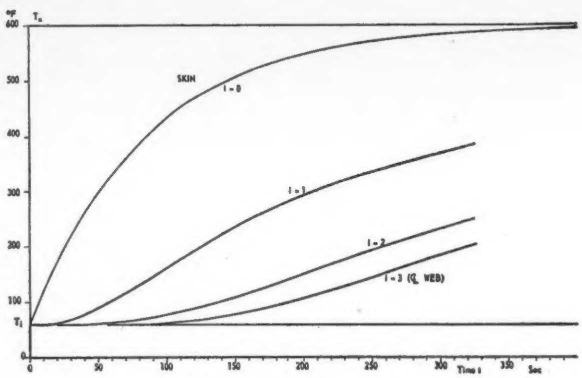


Figure 4
Temperature variation in spar web

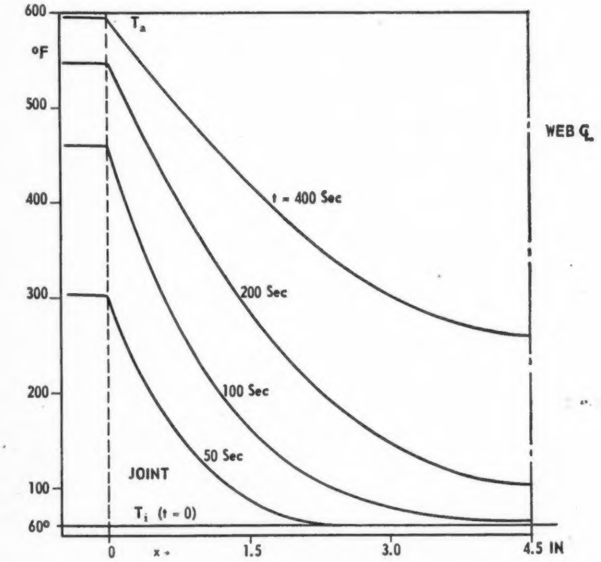


Figure 5
Temperature profiles in spar web

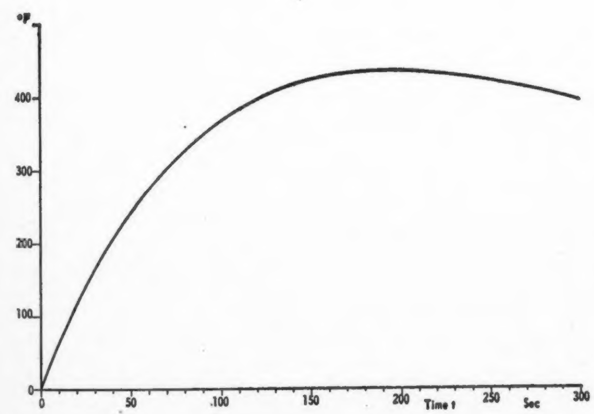


Figure 6
Variation of temperature difference between skin and web centre line

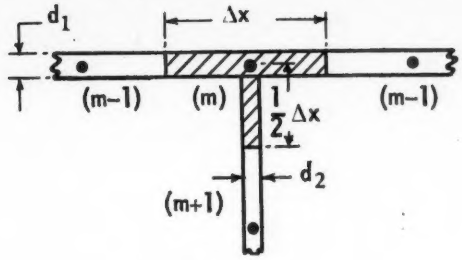


Figure 7
Intersection of skin and web

method, in References 7 and 8. The same data are used again, with the difference that the skin temperature will vary with the distance from the web. In the numerical work, the following equations shall be used.

(a) For points in the web region, Eq. (15) as previously.

(b) For points in the skin region, Eq. (21) becomes (with $r = 1/6$ and β as in the previous example),

$$T_i' = T_i \times 0.4573 + T_A \times 0.2093 + (T_{i-1} + T_{i+1}) \times 0.1667$$

(c) For point m at the junction of skin and web, a heat balance relation obtains similar to Eq. (23), but including the effect of convective heat transfer from the boundary layer into the skin (Figure 7).

$$T_m' = T_m(1 - 2r - \beta'\Delta t) + T_A\beta'\Delta t + T_{m-1}\, r\delta_1' + T_{m+1}\, r\delta_2' \quad (28)$$

As in Eq. (20) we may replace $(1 - \beta'\Delta t)$ by $e^{-\beta'\Delta t}$ for better accuracy, obtaining

$$T_m' = T_m(e^{-\beta'\Delta t} - 2r) + T_A(1 - e^{-\beta'\Delta t}) + T_{m-1}\, r\delta_1' + T_{m+1}\, r\delta_2' \quad (29)$$

where

$$\delta_1' = 2 \times 2d_1/(2d_1 + d_2),\ \delta_2' = 2d_2/(2d_1 + d_2),$$
$$\beta' = 2h/cp\,(2d_1 + d_2)$$

Substitute the data of the problem and put $m = 8$:

$$\delta_1' = 2 \times 0.75/0.85 = 1.765, \quad \delta_2' = 2 \times 0.1/0.85 = 0.235,$$

$$\beta' = \frac{90 \times 12 \times 2}{0.1406 \times 489.6 \times 0.85} = 37.0\ hr^{-1} = 0.01028\ sec^{-1}:$$

we shall use the same space intervals for skin and web, $\Delta x = 1.5$ in, $r = 1/6$ and $\Delta t = 20.17$ sec. Eq. (29) becomes then

$$T_8' = T_8 \times 0.4802 + T_A \times 0.1865 + T_7 \times 0.2942 + T_9 \times 0.0391$$

(d) At point 0 in the skin, half-way between webs, and at the centre line of the web, no conductive heat flow takes place and Eq. (16) applies.

Discussion of results

Comparing the results summarized in Table 4 with those of the preceding example, we see that the temperature drop in the skin is of the order of 30°F, i.e. small when compared with the web gradients. Within the time interval considered of 400 sec, the effect of finite skin conductivity has not reached back to point 0, the temperature there being as in the previous calculation. The same conclusions result from a comparison of Figures 8, 9 and 10 with Figures 4, 5 and 6. We see

TABLE 4
TEMPERATURE DISTRIBUTION IN WING SKIN AND WEB $T_A = \text{const} = 600°F$

Temperature at point		Elapsed heating time, sec						
i	x, in	0	60.5	121	181.5	242	302.5	363
0	0 (CL Skin)	60	333	468	535	568	584	592
2	3.0	60	333	468	535	568	584	592
4	6.0	60	333	468	534	567	583	591
6	9.0	60	332	466	530	564	580	588
8	12.0 (Joint)	60	307	436	504	539	557	569
9	13.5	60	101.5	185	257	312	354	388
10	15.0	60	63	88.5	130	176	222	264
11	16.5 (CL Web)	60	60	68	94	133	177	221
	$T_0 - T_8$	0	26	32	31	29	27	23
	$T_0 - T_{11}$	0	273	400	441	435	407	371

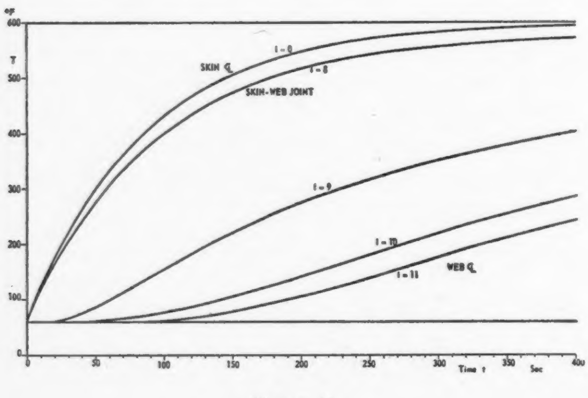


Figure 8
Temperature variation in wing skin and spar web

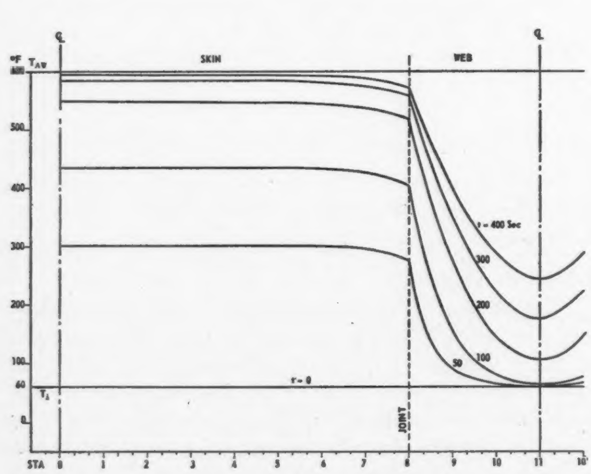


Figure 9
Temperature profiles in wing skin and spar web

that the heating process of the web is slightly retarded by the drop in skin temperature, but the overall temperature difference in the structure and the time at which it occurs remain practically unchanged.

The agreement of these results with those of References 7 and 8 is quite good, considering that the dimensions are slightly different and that the graphs in Parkes' work do not permit very accurate reading.

CONCLUDING REMARKS

The worked-out examples have demonstrated the manner in which the numerical procedure may be applied to various problems of transient heat flow. Once the difference equations have been set up, the calculations may be entrusted to inexperienced personnel. With the exception of the exponential functions, all the calculations in the tables were made on a 10 inch slide-rule.

A few remarks concerning the practical side of the calculations may not be amiss. The first decision to be taken when solving a problem concerns the choice of the space and time intervals. This will depend mainly

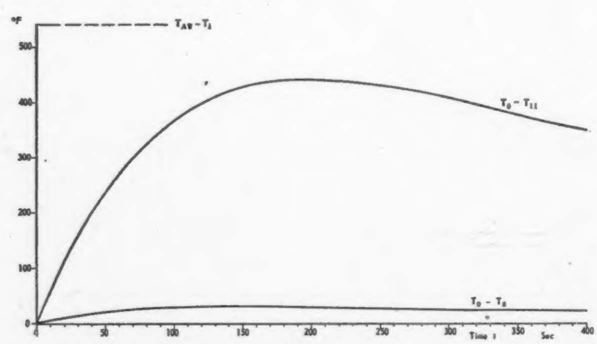


Figure 10
Variation of temperature differences in skin-web structure

on the accuracy desired. For an exploratory investigation, the number of space subdivisions need not be more than 3 or 4. The value of the modulus r will vary between $\frac{1}{2}$ and $\frac{1}{6}$, the first being the limit for stability when no convection is present and the last being used for best accuracy. The choice of r determines the time interval. When the period to investigate is long compared with the time interval chosen, it may be preferable to switch to longer time intervals (i.e. larger r) after a small number of initial steps. In the initial stage of heating or cooling, the temperature changes are generally much more rapid than later and must be analyzed in greater detail.

When a body is composed of several sections which cannot conveniently be subdivided into equal intervals, it may be preferable to slightly modify the original dimensions rather than have the inconvenience of unequal intervals.

With regard to temperature, it is often useful to refer all temperature changes to the largest temperature difference (e.g. ambient minus initial, in case of a constant ambient) which is taken as unity. Also, in the case of a constant ambient temperature, some simplification results by taking its value as a zero reference level.

ACKNOWLEDGMENT

The author wishes to acknowledge with thanks the permission given by Avro Aircraft Limited to publish this paper.

REFERENCES

(1) Kaye, J. – *The Transient Temperature Distribution in a Wing Flying at Supersonic Speeds*, JOURNAL OF THE AERONAUTICAL SCIENCES, VOL. 17, No. 12, DECEMBER 1950.

(2) Dusinberre, G. M. – *Numerical Analysis of Heat Flow*, McGRAW-HILL BOOK CO., NEW YORK, 1949.

(3) Jakob, Max – *Heat Transfer, Vol. 1*, JOHN WILEY & SONS, NEW YORK, 1949.

(4) McAdams, W. H. – *Heat Transmission, 3rd Edition*, McGRAW-HILL BOOK CO., NEW YORK, 1954.

(5) Hoff, N. J. – *Structural Problems of Future Aircraft, Appendix 1: Aerodynamic Heating and Thermal Stresses*, PROCEEDINGS 3RD ANGLO-AMERICAN AERONAUTICAL CONFERENCE, 1951.

(6) Parkes, E. W. – *The Alleviation of Transient Thermal Stresses*, AIRCRAFT ENGINEERING, FEBRUARY 1953.

(7) Parkes, E. W. – *Transient Thermal Stress in Wings*, AIRCRAFT ENGINEERING, DECEMBER 1953.

(8) Pohle, F. U. and Oliver, H. – *Temperature Distribution and Thermal Stresses in a Model of a Supersonic Wing*, JOURNAL OF THE AERONAUTICAL SCIENCES, VOL. 21, JANUARY 1954.

(9) Price, P. K. and Slack, M. R. – *Stability and Accuracy of Numerical Solutions of the Heat Flow Equation*, BRITISH JOURNAL OF APPLIED PHYSICS, VOL. 3, DECEMBER 1952.

ANNUAL GENERAL MEETING

CHATEAU LAURIER HOTEL
OTTAWA

27th and 28th May, 1957

May 27th	Morning–9.00 a.m. to 10.30 a.m. .	Business Meeting	
	Morning–10.45 a.m. to 12.45 p.m. .	Design and Structures	
	Afternoon–2.00 p.m. to 5.00 p.m. .	Test Pilots Section Materials	Concurrently
May 28th	Morning–9.00 a.m. to 12.00 noon .	Noise Antiicing and Deicing	Concurrently
	Afternoon–2.00 p.m. to 5.00 p.m. .	Aviation Medicine and Human Engineering Aerodynamics	Concurrently

The Principal Speaker at the Dinner will be

E. T. JONES

Director General of Technical Development (Air)
Ministry of Supply
President, Royal Aeronautical Society, 1956-57

Annual Awards will be presented at the Dinner

A METHOD FOR EVALUATING JET-PROPULSION-SYSTEM COMPONENTS IN TERMS OF MISSILE PERFORMANCE†

by R. W. Luidens* and R. J. Weber*

Lewis Flight Propulsion Laboratory, N.A.C.A.

INTRODUCTION

THE engineer studying engine components is continually faced with the problem of evaluating compromises between weight, drag, thrust and efficiency. Consider the engine inlet, for example. The research engineer or the airplane designer may have the choice of a low pressure recovery, low drag inlet or a high pressure recovery, high drag inlet of about equal weight, or possibly a high pressure recovery, low drag inlet of increased weight. One way to evaluate such a group of possibilities is to assume a missile mission and calculate the performance of the missile with each of the possible inlets. However, calculating complete missile performance is usually beyond the inclination of the engineer studying inlets. The purpose of this paper hence is to present a simple method for estimating the missile performance, when only the component performance is known. The paper will also discuss some examples illustrating the application of the proposed method.

Although the method is capable of handling any components of the installed engine, this paper considers primarily engine air inlets and exhaust nozzles. The performance of the component is, for example, for the inlet: the pressure recovery, drag and weight; and for the exhaust system: the velocity coefficient, expansion ratio, drag and weight. Airplane performance refers to its supersonic cruising range and its ceiling or maneuverability.

The equations that determine the airplane range and maneuverability are shown in Figure 1. The airplane range R is evaluated at cruise engine combustor temperature. The terms in the equation are the airframe lift-drag ratio L/D, the specific impulse of the engine I (that is, the pounds of thrust per pound of fuel per second), and the logarithm of a term involving the ratio of fuel weight to gross weight W_f/W_G.

Both the airplane ceiling (in feet) and maneuverability (that is, the number of g's it can pull in a turn without loss of speed or altitude) are measured by the maneuverability of the airplane G. This equation is

RANGE	MANEUVERABILITY
$R \approx L/D\ I\ \ln \dfrac{1}{1-\dfrac{W_f}{W_G}}$	$G = \dfrac{F-D}{W_G}$
EVALUATE AT CRUISE ENGINE COMBUSTOR TEMPERATURE	EVALUATE AT MAXIMUM ENGINE COMBUSTOR TEMPERATURE

Figure 1
Missile performance

evaluated at the maximum permissible engine cycle temperature in contradistinction to the cruise temperature that is used in the range equation. The terms in the maneuverability equation are the maximum engine thrust F, the steady-level-flight airplane drag D, and the airplane weight W_G.

A detailed development and discussion of the method described in this paper is given in Reference 1. Part of the general approach presented herein has been used by other investigators[2, 3].

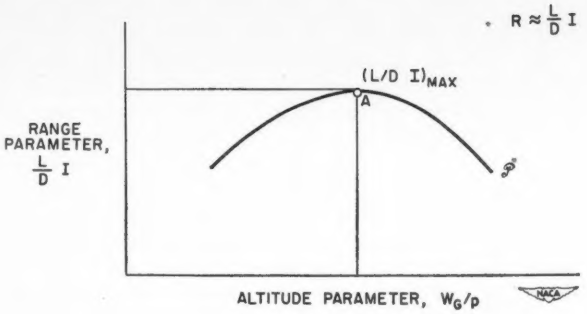
DESCRIPTION OF METHOD

In order to illustrate the approach taken to the problem of this paper, only the range equation will be discussed, with the understanding that similar arguments apply to the maneuverability equation. Further, in discussing the range equation, the inlet pressure recovery will be taken as the variable under consideration, with the understanding that it could equally well be many other variables, such as inlet drag or velocity coefficient of the exhaust nozzle. Weight variations can also be accounted for, although a weight term will not be shown in the subsequent equations.

Figure 2 reviews the flight condition of a given airplane to achieve maximum range. The terms in the range equation considered in this discussion are shown at the top of the figure. For a given airplane, to maximize

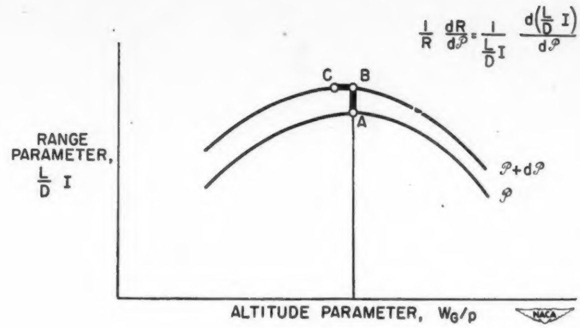
†Paper read at the I.A.S./C.A.I. International Meeting in Toronto on the 27th November, 1956.

*Aeronautical Research Scientist.



$$\frac{1}{R}\frac{dR}{d\mathcal{P}} = \frac{1}{\frac{L}{D}I}\frac{d\left(\frac{L}{D}I\right)}{d\mathcal{P}}$$

Figure 2
Flight condition for maximum range



$$\frac{1}{R}\frac{dR}{d\mathcal{P}} = \frac{1}{I}\left(\frac{dI}{d\mathcal{P}}\right)_{C_F=\text{CONST}}$$

Figure 3
Effect of engine component change on best flight condition

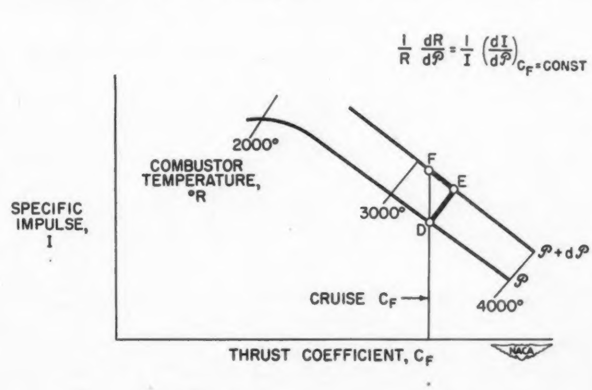
range, the product of L/D times I should be maximized. The range of a given airplane varies with the initial altitude of flight, as illustrated in the figure, where p is the altitude ambient pressure and W_G is the airplane weight. Of course, for maximum range, the airplane should fly at the peak of this curve. When the airplane weight decreases because of the fuel consumed, the altitude ambient pressure decreases a corresponding amount so that the ratio remains constant. The abscissa thus depends only on the airplane design and not on the fuel load aboard.

Another important point is that for a given airplane at a given flight Mach number, if W_G/p is constant, both the wing lift coefficient and the engine thrust coefficient are also constant. Hence, the airplane L/D and engine I individually stay constant over the flight as well as the product of L/D times I. In the approach taken herein, a reasonably good airplane is assumed to begin with, and the effect of making a small change to an engine component of this airplane is then evaluated. The effect on range is found by differentiation to arrive at the equation at the bottom of the figure. The denominators are the range and $(L/D)I$ of the airplane before a change is made.

Suppose for the sake of discussion that the change being considered is an increase in inlet total-pressure recovery, as illustrated in Figure 3. For the airplane with the improved inlet recovery, there will be a new curve of $(L/D)I$ against W_G/p, labeled $\mathcal{P} + d\,\mathcal{P}$. Also, the peak of the new curve will shift to a new value of W_G/p from point A to point C. But because operation is near the peaks of the $(L/D)I$ curves, the increase in $(L/D)I$ with the change in W_G/p from B to C may be neglected compared with the change in $(L/D)I$ at constant W_G/p from A to B. Evaluating only the change in $(L/D)I$ at constant W_G/p means that the airplane lift-drag ratio remains constant; hence its derivative is zero and it drops out of the differential equation. Also, the change in specific impulse must now be evaluated at constant thrust coefficient (recalling that if W_G/p is constant, then C_F is constant). This yields the equation at the bottom of the figure.

Consider now what must be done to the engine in order to maintain a constant thrust coefficient and what these changes do to the specific impulse. Engine performance may be plotted as specific impulse against thrust coefficient where the intermediate variable is the engine combustor temperature (Figure 4). Two curves are illustrated, one for the original engine ($\mathcal{P}$) and the other for the engine with the inlet having an improved pressure recovery ($\mathcal{P} + d\,\mathcal{P}$). If the combustor temperature is held constant after the pressure recovery has been increased, both the thrust coefficient and the specific impulse have increased, as shown by moving from point D to point E. The term in the equation at the bottom of the figure corresponding to this change is labeled DE. In order to reduce the thrust coefficient to the original value, as required, the engine must be throttled back, that is, the combustor temperature must be reduced as shown on the curve from point E to point F. The slope of the specific impulse with thrust coefficient is the term $\left(\frac{\partial I}{\partial C_F}\right)_{\mathcal{P}=\text{const}}$ and the distance to be moved along this curve is minus the increase in thrust that resulted from the increase in pressure recovery $\left(\frac{\partial C_F}{\partial \mathcal{P}}\right)_{T=\text{const}}$. The product of these two terms is labeled EF.

All the terms on the right-hand side of the equation have been evaluated and plotted so that evaluating the



$$\frac{1}{R}\frac{dR}{d\mathcal{P}} = \frac{1}{I}\left[\left(\frac{\partial I}{\partial \mathcal{P}}\right)_{T=\text{CONST}} - \left(\frac{\partial I}{\partial C_F}\right)_{\mathcal{P}=\text{CONST}}\left(\frac{\partial C_F}{\partial \mathcal{P}}\right)_{T=\text{CONST}}\right]$$

Figure 4
Effect of component change on engine

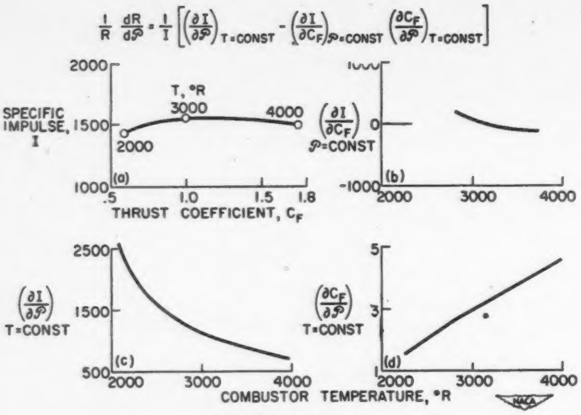


Figure 5
Ramjet engine performance and derivatives
$M_0 = 4.0$

equation is only a matter of taking values from a curve and performing a few simple multiplications and additions.

A typical plot of such performance and performance derivatives for a ramjet engine is presented in Figure 5. Part (a) is the engine performance in terms of thrust coefficient and specific impulse. Part (b) is the slope of the curves of part (a). Parts (c) and (d) are the derivatives of the thrust coefficient and specific impulse with pressure recovery. These are all the values needed to evaluate the equation at the top of the figure except $d\mathscr{P}$, which must be determined from experimental work or separate calculations. Reference 1 also gives derivatives with respect to exhaust nozzle velocity coefficient and nacelle drag coefficient for flight Mach numbers from 1.0 to 5.0. Similar data are also given therein for a turbojet engine.

So much for the method. The development has been illustrated only for the range equation; it can also be applied to the maneuverability equation. Also, its use was illustrated only with inlet pressure recovery; performance of the exhaust nozzle and other engine components can also be handled, including weight. A complete derivation of the method is given in Reference 1; some of the final general equations from that report are shown in Table 1.

APPLICATIONS OF METHOD

The preceding section describes a technique for evaluating engine components. This section will present several numerical examples to illustrate typical applications of the technique. It is hoped that these examples are not merely illustrative but are also of interest in themselves.

The flight vehicle considered will be a long-range ramjet powered missile of fixed size. Gross weight is assumed to be initially 100,000 pounds but is allowed to vary somewhat as required by engine modifications. Therefore, Equation (3) of Table 1 is used. The engine

TABLE 1
AIRPLANE PERFORMANCE RELATIONS

(Evaluate at cruise combustor temperature except terms involving $C_{F,max}$)

(a) Fixed-size airplane with constant initial gross weight

$$\frac{1}{R}\frac{dR}{dX} = \frac{1}{I}\left\{\left(\frac{\partial I}{\partial X}\right)_{t,C_D} - \left[\frac{I}{C_F} - \left(\frac{\partial I}{\partial C_F}\right)_{X,C_D}\right]\frac{dC_D}{dX} - \left(\frac{\partial I}{\partial C_F}\right)_{X,C_D}\left(\frac{\partial C_F}{\partial X}\right)_{t,C_D}\right\} - \frac{1}{kW_g}\frac{dW_e}{dX} \qquad (1)$$

$$\frac{dG}{dX} = \left[\left(\frac{\partial C_{F,max}}{\partial X}\right)_{C_D} - \frac{dC_D}{dX}\right]\left(\frac{1}{\frac{L}{D_t}}\right)\frac{1}{C_F} \qquad (2)$$

(b) Fixed-size airplane with fixed initial fuel weight and variable initial gross weight

$$\frac{1}{R}\frac{dR}{dX} = \frac{1}{I}\left\{\left(\frac{\partial I}{\partial X}\right)_{t,C_D} - \left[\frac{I}{C_F} - \left(\frac{\partial I}{\partial C_F}\right)_{X,C_D}\right]\frac{dC_D}{dX} - \left(\frac{\partial I}{\partial C_F}\right)_{X,C_D}\left(\frac{\partial C_F}{\partial X}\right)_{t,C_D}\right\} - \frac{1}{kW_g}\left(\frac{W_f}{W_g}\right)\frac{dW_e}{dX} \qquad (3)$$

$$\frac{dG}{dX} = \left[\left(\frac{\partial C_{F,max}}{\partial X}\right)_{C_D} - \frac{dC_D}{dX} - \frac{C_{F,max}}{W_g}\frac{dW_e}{dX}\right]\left(\frac{1}{\frac{L}{D_t}}\right)\frac{1}{C_F} \qquad (4)$$

(c) Variable-size airplane with constant acceleration potential and constant payload weight

$$\frac{1}{R}\frac{dR}{dX} = \frac{1}{I}\left\{\left(\frac{\partial I}{\partial X}\right)_{t,C_D} - \left[\frac{I}{C_F} - \left(\frac{\partial I}{\partial C_F}\right)_{X,C_D}\left(1 - \frac{C_F}{C_{F,max}}\right)\right]\frac{dC_D}{dX} - \left(\frac{\partial I}{\partial C_F}\right)_{X,C_D}\left[\left(\frac{\partial C_F}{\partial X}\right)_{t,C_D} - \frac{C_F}{C_{F,max}}\left(\frac{\partial C_{F,max}}{\partial X}\right)_{t,C_D}\right]\right\} -$$

$$\frac{1}{k}\left\{\frac{1}{W_g}\frac{dW_e}{dX} - \frac{1}{C_{F,max}}\left(\frac{W_e}{W_g} + \frac{W_{pl}}{W_g}\right)\left[\left(\frac{\partial C_{F,max}}{\partial X}\right)_{t,C_D} - \frac{dC_D}{dX}\right]\right\}$$

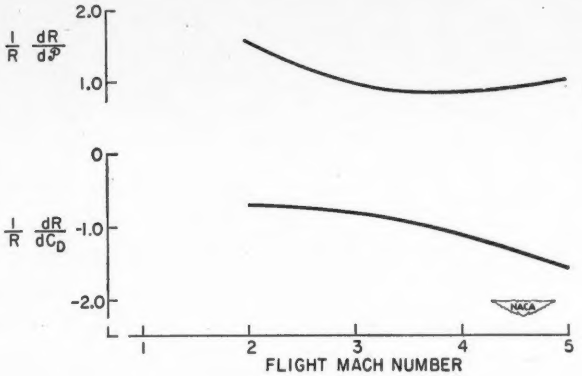


Figure 6
Effect of inlet pressure recovery and drag
[Note: C_D based on inlet frontal area]

is assumed to have a cruising combustion temperature of 3500°R. The examples will deal in turn with each of the three major components of the ramjet engine: inlet diffuser, combustion chamber and exhaust nozzle.

Comparative importance of inlet pressure recovery and drag

The thrust and specific impulse of a supersonic jet engine depend to a great extent on how successfully the diffuser converts the velocity head of the captured air into pressure. This, of course, is particularly true of a ramjet engine, which has no mechanical compressor to raise the air pressure. Intensive effort has therefore been devoted to the development of efficient inlet diffusers that provide high pressure recoveries. Unfortunately, it is usually the case that inlets possessing good pressure recoveries also incur large external cowl drags which tend to negate the benefits of high recovery. This effect (plus many others, of course) must be considered in arriving at a satisfactory inlet design.

The mathematical technique described in this paper may be used as a helpful guide in making a compromise between the factors of pressure recovery and cowl drag. For this purpose, Figure 6 may be constructed, which indicates the effect on relative missile range of a unit increment in either pressure recovery or cowl drag coefficient. Note especially that a given increment in cowl drag coefficient produces a relatively greater loss in range as flight speed is increased.

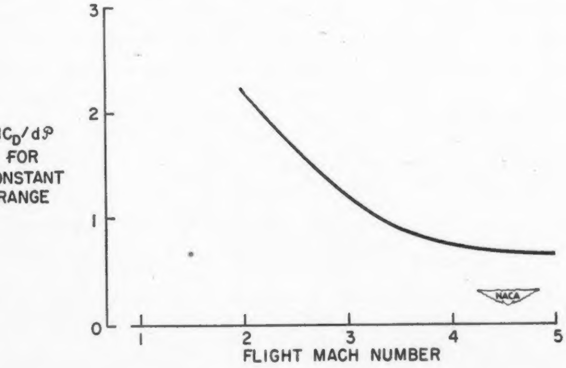


Figure 7
Inlet break-even condition—ramjet missile

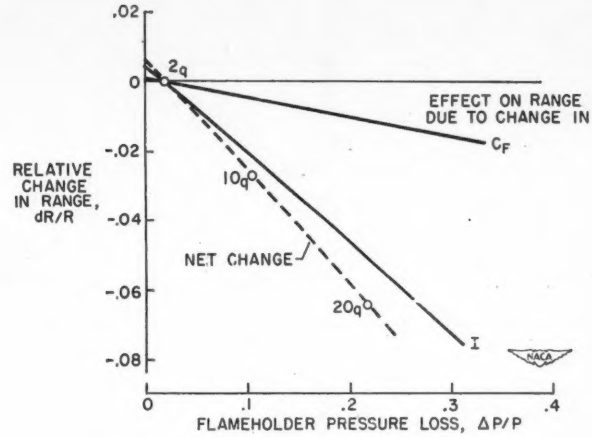


Figure 8
Effect of flameholder drag—ramjet missile; $M_0 = 4.0$

The information of Figure 6 may be combined into a single curve, which presents what has been termed the "breakeven condition" (Figure 7). Here is shown the ratio of the increment in drag coefficient to the increment in pressure recovery that must be preserved to maintain constant range when an inlet is redesigned or modified at a given flight Mach number. (It is not implied that the range is the same at different Mach numbers.) The figure shows that, at low Mach numbers, a given increment in pressure recovery may be accompanied by a large increase in drag coefficient without harming missile range. At higher Mach numbers, however, only a small increase in drag coefficient is tolerable for the same increment in pressure recovery. It may then be concluded that, at high Mach numbers, a good inlet should be compromised more in the direction of low drag than is required at lower speeds.

Effect of flameholder drag

When conventional fuels are used, it is necessary to provide flameholding elements at the combustor entrance in order to stabilize the flame and promote efficient combustion. Such flameholders partially block the airflow, creating turbulence and resulting in a loss in total pressure. This total-pressure loss is reflected directly in lower engine thrust and specific impulse (assuming a constant combustion efficiency). However, use of flameholders with greater amounts of flow blockage (and hence, greater total-pressure losses) usually results in an improvement in combustion efficiency with a consequent beneficial effect on specific impulse. The combustion-chamber designer must, therefore, often compromise between a low-drag flameholder with small pressure losses and a high-drag flameholder that provides better combustion efficiency.

The change in missile range resulting from variations in flameholder total-pressure loss is shown in Figure 8. It is assumed in this figure that the combustion efficiency is constant. (Also, the effect of flameholder-weight variations is neglected.) The circled points indicate the flameholder drag coefficient in units of the incompressible dynamic head of the air upstream of the flameholder (for a combustor-inlet Mach number of 0.125). The

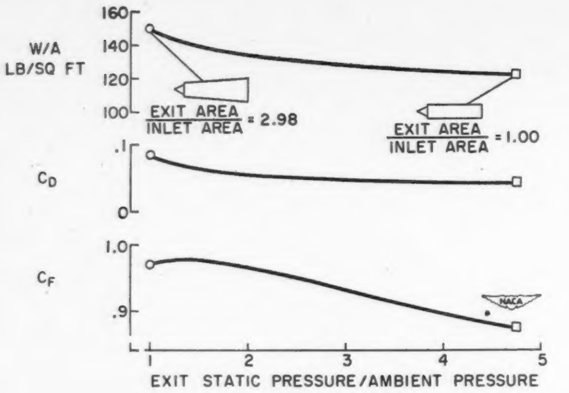


Figure 9

Effect of nozzle expansion ratio—ramjet engine; $M_0 = 4.0$
[Note: *I* varies in same proportion as C_F]

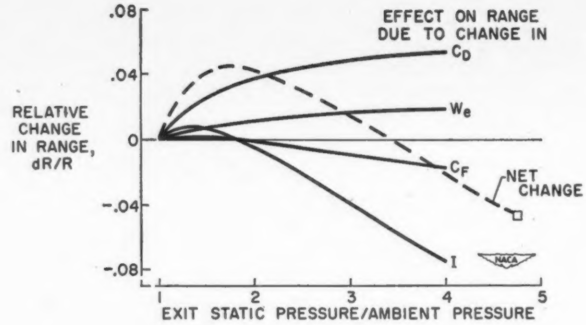


Figure 10

Effect of nozzle expansion ratio—ramjet missile; $M_0 = 4.0$

drag coefficient for the reference flameholder is taken as 2, with a corresponding pressure loss of 0.02. Increasing the drag coefficient to 20 (pressure loss of 0.21) reduces the range by 1% because of the loss in thrust and by 5% because of the loss in specific impulse, for a total reduction in range of 6%. If experiments should now show that this change in flameholder drag had increased the combustion efficiency by 8%, for example, we could then conclude that the missile range had been improved by 8 − 6 = 2% because of the change to a high-drag flameholder.

It should be observed that the importance of the flameholder pressure loss is a function of the flight Mach number (similar to the case of inlet pressure recovery). At high flight speeds, greater pressure losses can be tolerated without serious consequences.

Effect of nozzle expansion ratio

As flight speed increases, the pressure ratio afforded by ram effect soon reaches very large proportions. For example, at a Mach number of 4, the ideal ratio of nozzle total/free-stream static pressure is 157. After undergoing reasonable losses in the diffuser and combustion chamber, the pressure of the gas entering the exhaust nozzle is still of the order of 70 times ambient pressure. Maximum internal engine thrust and specific impulse is obtained by using a nearly fully expanding convergent-divergent nozzle. The exit area of such a nozzle would be about three times the frontal area of the inlet. A considerable portion of engine weight and nacelle drag could be saved by using a smaller, incompletely expanding nozzle.

This situation is illustrated in Figure 9, where the estimated engine weight per unit frontal area, nacelle drag coefficient, and internal thrust coefficient (based on inlet frontal area) are given as functions of the ratio of nozzle exit pressure to ambient pressure. When this ratio is unity, the exhaust gases are completely expanded by the nozzle. If the nozzle is cut back until it is no larger than the inlet, the pressure of the gas leaving the nozzle is 4.75 times ambient. At this condition, the engine weight has been reduced by 20% and the nacelle drag by 50%. At the same time, however, failure to expand the gases completely reduces both the internal engine thrust and the specific impulse by 10%. (The initial slight improvement in internal thrust results from the assumption of a nozzle velocity coefficient less than unity.)

In order to determine the nozzle expansion ratio for best range, it is necessary to consider simultaneously the effect on the missile of changes in C_F, I, C_D, and W_e. The effect on range of each of these parameters is shown in Figure 10. Summing the range increments for each parameter gives the total change in range as indicated by the dashed line. Reducing the nozzle-exit area from the fully expanding condition results in a range improvement of over 4% at an exit pressure ratio of 1.75. This corresponds to an exit area reduction of 33% from that for full expansion. Further area reductions decrease the range; however, an exit pressure ratio of 3.40 (which is an exit area reduction of 58%) still provides as long a range as does full expansion. An exit area equal to inlet area would be much too severe a reduction, resulting in a range 5% less than that for full expansion and 9% less than that for the optimum expansion ratio.

CONCLUSION

With the aid of a number of simplifying assumptions, an analytical technique has been developed to evaluate modifications in engine components in terms of the performance of the engine-airframe combination. Although the present discussion has emphasized application to ramjet missiles, the method is equally applicable to turbojet aircraft. The technique appears most useful for workers engaged in research and development of inlet diffusers and exhaust nozzles. However, the presented relations are general enough to apply to any engine component.

REFERENCES

(1) Weber, Richard J., and Luidens, Roger W. – *A Simplified Method for Evaluating Jet-Propulsion-System Components in Terms of Airplane Performance*. NACA TN 3834, 1956.

(2) McLafferty, George – *Simplified Methods for Comparing the Performance of Turbojet Inlets*. Rep. SR-13534-11, Res. Dept., United Aircraft Corp., Feb. 1, 1955.

(3) Melrose, G. B., and Jackes, A. M. – *The Effects of Changes of Design Parameters on Aircraft Cruise Range*. Design Note No. 11, Bell Aircraft Corp., Oct. 4, 1954.

C.A.I. LOG

SECRETARY'S LETTER

UNSOLICITED TESTIMONIALS DEPARTMENT

It is not often that we get bouquets thrown our way and it was very gratifying to receive the following: "Many thanks for the complimentary copy of your Journal that was sent to me. It is the first time that I have had the pleasure of reading this Journal and am very favourably impressed by the scope and quality of the material in this issue. The index for Volume 2, which was enclosed, is impressive and makes me feel that I have missed much in the past by not reading this Journal."

So you see, gentle reader, somebody likes us. I may add that he has applied for admission.

ANNUAL DUES

In March we send to all members their annual dues bills for the new year 1957-58, which begins on the 1st April. Many members – I should say the great majority – pay their dues fairly promptly and for a while our Headquarters staff is inundated with payments, in the form of cheques, money orders and even cash. We deal with them as expeditiously as we can, sending out membership cards and, when requested, receipts in acknowledgment of these payments. But because of the quantity and because this hits us when we are very busy getting ready for the Annual General Meeting, we cannot handle all the necessary bookkeeping as quickly as we should like. I mention this in making a plea for patience. I am not suggesting that people should put off paying their dues – and then forget about it altogether – but I hope that members will bear with us if we do not acknowledge their payments for two or three weeks.

In case anyone wonders what has happened to the "Journal Card" which was attached to last year's dues bill, the story is this. The Post Office is not particularly concerned with who pays for what, but it is interested in handling the mail; it will give us a special rate on Journals sent to people who want them – and say so – but we get no reduction on Journals sent to people who have not specifically asked for them. So last year we attached a card to the dues bill, on which each member could indicate whether he wanted the Journal or not. These cards were checked by the Post Office; and they will be rechecked as more cards are received from new members. However, the Post Office has said that we do not have to collect these cards from everybody every year and, for this year at any rate, those who have already returned cards will not be asked to do so again.

NEWS OF MEMBERS

In the "Members" section of the Journal, we give short items of news about members who have moved or have received honours or appointments. People like to learn that "Old So-and-so" has received some long-service award or "Young Whatsisname" has become General Manager.

Please give us your news. Having no organized intelligence service, we work under a severe handicap. Branch Secretaries are our chief source of information; company house journals are another; and sometimes even the members tell us themselves, but usually only when a change of mailing address is involved.

NEWS OF SUSTAINING MEMBERS

And I would ask our Sustaining Members to give us their news too. We will gladly publish news having technical significance to the Canadian aeronautical scene. Such things as the building of new plant, the opening of new facilities, the development of new equipment (and its technical details), the step by step emergence of a new aircraft or a new engine, the introduction of new equipment by operators – all these things are of wide interest. Sustaining Members should remember that, as members of the Institute, they are very welcome to use the Journal for announcements of their technical contributions. Directly or indirectly these contributions affect us all.

BRANCHES

NEWS

Ottawa—Reported by S/L W. M. McLeish

January Meeting

The January meeting, held at Beaver Barracks on Wednesday, 16th January, was attended by a rather small audience, but when it is recalled that Ottawa was in the midst of a record-breaking cold wave that week, it is encouraging that 40 members were able to make it. The speaker of the evening, Mr. J. H. "Red" Lymburner, a Director of TransAir Limited, and his subject, "Surveying the DEW Line", were introduced by G/C W. P. Gouin, Vice-Chairman of the Branch. The introduction recalled Mr. Lymburner as a pioneer Canadian bush pilot and also as second pilot, and captain, respectively, on two Antarctic expeditions under Ellsworth in the 1930's.

Mr. Lymburner used a tape recording to introduce his topic, a CBC recording of one of Max Ferguson's "Rawhide" versions of Canadiana entitled "DEW Line". Briefly, imagine several million dew worms in a trough two feet wide, one foot deep, filled with first-grade top soil, and stretching along a far-northern parallel from the Atlantic to Alaska. To make Rawhide's dew line work, simply fly toward the line from the north and, at some point removed from the line, the shock waves emanating from the aircraft should arrive at the cross-country trough with the delicate influence of falling dew. This, of course, causes the dew worms to start surfacing en masse and, with a suitable quantity of photoelectric cells, the defence system is motivated. Rawhide pokes fun at many sides of Canadian life and his dew line was in reality a dig at the security curtain which the DEW Line requires. Mr. Lymburner was faced with the security problem in his paper; he was obviously restricted from discussing the details of Operation Survey. However, he did outline the chief obstacles during the operation – transportation between sites, Arctic weather, and the supply difficulties.

Mr. Lymburner was associated with Spartan Air Services in 1955 when the company became a prime contractor to Western Electric for all the survey work on the DEW Line. The approximate locations of the sites had been completed by Western Electric and it was Spartan's responsibility to produce the engineering data in detail for the construction contractors. The siting consisted of the surveying of runways, roads, building foundations and beacon locations. As Project Manager, Mr. Lymburner was required to coordinate the activities of four companies – Spartan Air Services on ground and photographic survey; Aero Services Ltd., Philadelphia, on photo interpretation; a New York consulting engineering firm; and Canadian Aero Services Ltd. who handled the project administration.

Because the work was restricted to the period between February and June, 1955, it was extremely difficult to obtain the services of skilled engineers with Arctic experience. The purchase of Arctic equipment also taxed the management and, unlike the personnel problem, it was never satisfactorily solved. With the main base at Churchill, the operation commenced in March and was plagued continually by transportation difficulties. The support for the survey parties was adequately provided with an aircraft for each party, plus one for the project manager. However, due to bad weather, aircraft unserviceabilities, misplaced gasoline caches and unreliable navigation procedures, the manager was often required to release his aircraft for direct support duties. This necessitated the use of chartered aircraft, and on one occasion resulted in a 2,700 mile flight to progress 150 miles eastward along the line. This was due to the lack of east-west travel out of Churchill, which obliged the traveller to move south from Churchill to link with a trans-Canada service to points such as Ottawa, Winnipeg or Edmonton, and then north again via chartered aircraft. The chief problem with Arctic navigation was the finding of a survey party or fuel cache by map reading over landscapes which changed with every storm.

In spite of such adversities, the task was completed on schedule by June, 1955, and the engineering data was made available later in the year. Mr. Lymburner pointed out that his previous Arctic experience, which had been acquired at a leisurely pace with exploration parties, was not as useful as had been anticipated. On the other hand, Operation Survey had to follow a strict timetable to beat the summer break-up, which provided a leeway of only a few days.

Mr. Lymburner completed his lecture by presenting a number of coloured slides taken during the operation. These slides provided vivid pictures of Arctic wilderness and although he could not identify the locations for security reasons it made little difference to the audience because of the monotonous similarity of each site.

Following a short question period, the speaker was thanked and the meeting adjourned at 10.30 p.m.

Halifax—Reported by E. C. Garrard

First January Meeting

We had quite a successful opening meeting on the 9th January attended by a total of approximately 50 members, prospective members and guests. A Program Committee and Nominating Committee were appointed and it was agreed by the members present that the Interim Committee continue to function until April next, by which time we should be able to go through the procedure of Article 10 of the Branch Regulations to elect officers for 1957-58.

The writer gave a talk on "How the Design of an Airliner Starts" and described as simply as possible the procedure which has to be followed in order to prepare the first general arrangement drawing of any aircraft.

Second January Meeting

Our second meeting was held at the Nova Scotia Technical College, Halifax, on the 30th January, when Mr. E. J. Lynch, Chief Ground Test Engineer of Avro Aircraft, lectured on "The Structural Testing of Modern Aircraft".

The audience of about 50 members, applicants and guests obviously enjoyed every minute of a truly masterly exposition of a complex subject. Our thanks are due to a member of the Toronto Branch and to Avro Aircraft Ltd. for such an excellent paper.

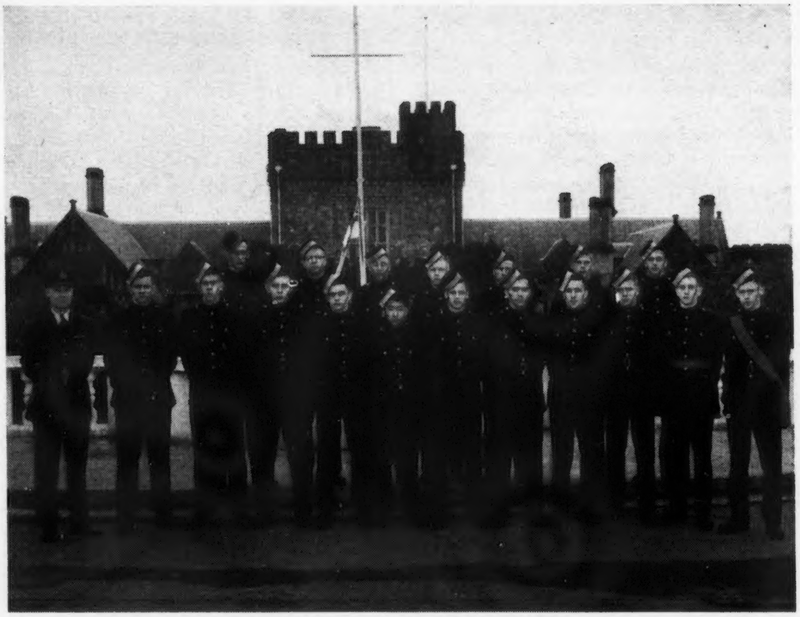
Vancouver—Reported by R. J. McWilliams

January Meeting

The Vancouver Branch was very pleased to welcome Mr. H. C. Luttman, Secretary of the Institute. His visit was well-timed, since it coincided with the regular meeting of the Branch.

Earlier in the day, Mr. Luttman and the writer had visited our very enthusiastic Student Section at Royal Roads. As usual, the C.A.I. visitors were greeted warmly and treated hospitably. A report by the Student Section of this visit appears following this report.

The evening meeting was held in the Stanley Park Sports Pavilion and was attended by 85 members and guests. A



Vancouver Branch—Student Section members at Royal Roads. Front row (l to r): F/L K. E. Lewis, Cadets A. G. A. Pearson, T. S. Neill, G. G. Hopp, P. J. Dawson, K. Ujimoto, M. W. Stedman, A. O. Manson, L. C. Cook, H. H. Sherwood, R. D. McCracken, J. C. McMeekin. Back row (l to r): Cadets D. H. Morrow, J. M. Cooling, R. J. Lawson, K. A. McLean, R. J. Houston, P. Scholz, J. B. Klassen. (Missing: Cadets C. A. Crow and F. C. Johnson).

short business session preceded a few well-chosen remarks by Mr. Luttman. He spoke of the activities of the Institute and of the forthcoming Institute meeting in Winnipeg. He retired leaving us well-pleased with our efforts, as a good representative of Headquarters does.

Our speaker for the evening was Mr. J. S. Brinkman, Manager, Customer Sales, U.A.L. Denver, Colorado. Mr. Brinkman was introduced by Mr. T. Cox, Sales Manager, U.A.L. Vancouver.

Mr. Brinkman chose as his subject "Space Control thru' R.A.M.A.C." and divided his talk into two sections – the first dealing with the problem and the second dealing with an answer to the problem. The control of airlines reservations is becoming increasingly difficult. The manpower requirements of present systems, particularly at the control centre, and the paper work required are reaching formidable proportions. The integration and coordination of field sales offices, spread across the continent within and beyond the borders of the U.S.A., creates a staggering problem. Mr. Brinkman was able to express these and related problems very lucidly and simply as a plain, ordinary, inventory control problem. Why not make use of the untold man hours of work which have gone into the development of modern Inventory Control procedures? For Inventory Control read Space Control.

Accuracy is paramount, Speed essential.

U.A.L.'s answer to this problem is Random Access Memory Accounting, one of the latest developments in electronic data processing, which can handle today's workloads and also the foreseeable workloads of the jet age more efficiently and more economically.

The new space control system is divided into three sections. Firstly, there is the Central Control office (with RAMAC); secondly, the Telephone Sales offices using I.B.M. punched cards for reservations transactions, referred to as I.B.M. offices; and thirdly, the offices that use the teletype instead of the punched card, referred to as non-I.B.M. offices.

The sequence of steps which the space control system must go through are similar to those processes used by the human brain. It must listen to information or instructions given; it must memorize; it must act and, if necessary, calculate and make decisions; and finally, it must be able to give answers and information requested.

RAMAC can store 5,000,000 characters and can perform a "read" or "write" operation in the average time of half a second. As an example of "talking", it completes a typed daily summary of 300 trips, containing 1,000 flight segments in less than 10 minutes.

Like the human, RAMAC tires if worked too long; it can become temperamental. Hence a standby RAMAC is installed. Like the human, RAMAC is paid overtime if worked too long. It was estimated that the system will cost $20,000 each month and this figure will increase appreciably if overtime is required. U.A.L. bought RAMAC purely on the basis of immediate savings.

Mr. Brinkman ended his talk on a cautious note. RAMAC is not a cure-all. It is only as accurate as the information which it receives.

The discussion that followed was adequate expression of audience interest and it emphasized the three areas of major interest – the effect of this automation on reservations personnel; the problems associated with this application of electronic data processing; and the potential applications of RAMAC, particularly for cargo space control and statistical analysis and reports.

Our thanks were expressed by the Secretary, who commended U.A.L. for their progressive outlook in the re-employment of personnel made redundant by RAMAC.

The meeting adjourned for coffee and sandwiches.

Student Section January Meeting
Reported by A. O. Manson

On January 18, 1957, the Royal Roads Student Section of the Vancouver Branch, C.A.I., was honoured by the presence of Mr. H. C. Luttman, Secretary of the C.A.I., and Mr. R. J. McWilliams, Secretary-Treasurer of the Vancouver Branch, C.A.I. Arriving shortly before lunch, the guests were met and entertained in the Wardroom of the Castle by F/L K. E. Lewis and eleven Student members.

Immediately after lunch, a meeting was held in the Conference Room with Mr. Luttman, Mr. McWilliams, F/L Lewis and nineteen Students present. The Chairman, Cadet M. W. Stedman, opened the meeting by calling upon the Secretary to read the Minutes of the last meeting. The Minutes were read and adopted.

Cadet P. J. Dawson then presented a report on the membership of the Section. He stated that 7 cadets hold Student membership cards, while 15 other cadets have their applications under consideration at the moment.

Cadet Stedman then introduced the guest speaker, Mr. Luttman. Mr. Luttman first stated the aims and the advantages of belonging to the C.A.I. He especially emphasized the importance of the Student Sections, particularly in a place such as a Military College. This, he said, will help to decrease the gulf between industry and the Services. Not only do cadets receive the opportunity to meet senior people in the aeronautical profession, but in attending C.A.I. meetings and activities, they are working

hand in hand with their civilian counterparts, an association which will tend to provide an outlook on both civilian and Service aeronautical problems.

Mr. Luttman then presented a brief account of the organization and administration of the Institute by means of the Council, Executive Committee and the Branches of the C.A.I. It was particularly interesting to note that the first Institute "Section" (Test Pilots) has been formed. Mr. Luttman stated that, in future, other Sections, such as Rocketry and Electronics, might well be formed. Mr. Luttman was then thanked by Cadet Stedman for his informative address.

Mr. McWilliams was then called upon to say a few words. He stressed the importance of sending Minutes of meetings and any papers presented by cadets to the C.A.I. Journal. This would give the other members of the Institute an idea of the activities of the Royal Roads Student Section.

Mr. McWilliams also stated that it might be possible in the near future to obtain Mr. Tex Johnston, Chief Test Pilot of Boeing Aeroplane Co. in Seattle, to address the Student Section at Royal Roads.

Cadet R. D. McCracken rose to express a vote of thanks to Mr. McWilliams for his timely assistance in organizing a tour of the Boeing Aeroplane Co. plant in Seattle for a number of the Student members.

At 1415 hours, the meeting was adjourned by Cadet C. A. Crow and seconded by Cadet G. G. Hopp. Cadet Stedman, after thanking the two guests for the interest they have shown and the help they have given in the formation of the Student Branch, adjourned the meeting.

Cold Lake—Reported by R. W. Ellard

January Meeting

The January meeting of the Cold Lake Branch was held in the Library of the Sergeants Mess at 8 pm on the 16th January, 1957.

After a short business meeting, the Branch Chairman introduced Mr. H. C. Luttman, Secretary of the C.A.I., who gave a most interesting talk on the inception, growth, aims and achievements of the C.A.I., which was much appreciated by the members present.

The Branch Chairman thanked the speaker and a lively question period followed, during which refreshments were served.

Thirty members attended this meeting.

Winnipeg—Reported by D. C. Marshall

January Meeting

On Tuesday, January 29, 1957, at the Westinghouse Auditorium, the Winnipeg Branch of the C.A.I. had as their guest speaker, Mr. J. F. Graham, Senior Service Representative for Helicopters of Canadian Pratt & Whitney. Mr. Graham's talk mentioned some of the early history of helicopter development and some of the design problems which were encountered. It covered in more detail problems of operation and of maintenance and overhaul. Mr. Graham also mentioned the helicopter's unique capabilities, which are the result of its ability to hover and to move in any direction.

Since serious helicopter design and construction did not take place until the late '30's, it is unfair to compare rotating wing aircraft development with fixed wing aircraft development. The Germans made a successful helicopter in 1937. In the Western Hemisphere, the first successful helicopter was Sikorski's VS300, which flew in 1939.

A major problem in helicopter design is the control system. Early attempts at flight resulted in a slow roll-off the ground, instead of controlled flight. The cause was established as the difference in lift which resulted from the difference in airspeed between the advancing and receding rotor blades. The solution was Cierva's flapping hinge, which is still used.

The history of helicopter development shows steady progress from the VS300, which flew at 40 mph, to the S56, which has a top speed of over 160 mph with no payload.

Much of the early commercial helicopter operation in Canada was mountain survey work. Payloads were limited and the main advantage of the helicopter was its ability to get a man and his survey equipment to inaccessible places. This job has now been expanded to the point where helicopters are being used for seismic exploration. Survey points are one-third of a mile apart and the surveyor's transit is replaced by a ton and a half of equipment.

Helicopter ambulance service for some remote areas is now a reality. This could be expanded to cover metropolitan areas. Another proposed use for helicopters is that of airport fire-tender, where fences and other obstructions slow down ground equipment.

Mr. Graham closed his talk with a film on helicopter operation in remote areas and over the Gulf of Mexico. In the latter area, a helicopter taxi service saves costly drilling time by speeding technicians and parts to rigs drilling for oil under the Gulf.

Mr. W. E. Robinson, Chief Engineer of Bristol Aircraft (Western) Ltd., thanked Mr. Graham for his talk which had items of interest and of technical information for everyone present.

Edmonton—Reported by H. E. Davenport

February Meeting

S/L J. A. G. Diack, Chairman of the Programme Committee, introduced the guest speaker, Mr. C. B. Falconar, at a

At the Cold Lake January Meeting (l to r): W. A. Haynes (Education Committee), R. W. Ellard (Secretary), S/L B. D. MacArthur (Councillor), W/C R. D. H. Ellis (Program Chairman), H. C. Luttman (Secretary C.A.I.), S/L R. G. Christie (Chairman), D. L. Wallis (Councillor).

meeting of the Edmonton Branch held on the 15th February. It was pointed out that Mr. Falconar has a long background of glider experience and was a member of the Canadian glider team at the international soaring meet in France last year.

The speaker, who had chosen as his subject, "Progress in Soaring", covered the development of the glider from the very early days and discussed the various types of gliders. It was shown that Germany developed gliding greatly after the first World War. The Canadian Gliding Association was formed in 1944, after which several gliding clubs in eastern Canada were formed. These clubs, said Mr. Falconar, had subsequently developed soaring to a high degree and currently hold some fine records; they have also done well in international events. Mr. Falconar next discussed the theory of glider flight, particularly as regards the various types of air motion that make soaring possible.

Apart from the better-known thermal and upgrade currents, it was shown that wave-form soaring made it possible to reach very great heights. Gliders using the dynamics of this phenomena have already reached a height of 45,000 ft and the ultimate possible altitude attainable is believed to be much greater. Development of pressurization is now under way for this purpose and these high altitude gliders are currently being used for scientific weather research.

It was shown that inately, glider pilots require a much greater knowledge of meteorological science than is necessary for a powered aircraft pilot. Quite large soaring gliders were discussed, which have wing spans in the order of 100 to 120 ft and weigh 3,500 lb, which have been built for research in the various aeronautical sciences.

Mr. Falconar next gave an excellent and detailed account of the 1956 international soaring meet in France, which was shown to be highly competitive with a great number of nations represented. Coloured pictures dealing with the meet were next projected, which illustrated clearly the various gliders and other data relating to the meet. At the conclusion of the talk, Mr. Falconar was ably thanked by Mr. W. Lloyd, our Treasurer.

SECTIONS

NEWS

Test Pilots—Reported by F/L J. C. Henry

This is the first newsletter of the newly-formed Test Pilots Section of the C.A.I. and it seems fitting that a review of events leading to its formation should be included.

On the 2nd March, 1956, a meeting of all Canadian civilian and military test pilots was held at RCAF Station Rockcliffe for the purpose of acquainting the test pilots with Canadian flight test facilities, the specifications in use, new pilot equipment, and for a general discussion of flight test problems in Canada. Out of this meeting there came a proposal to form a Canadian Test Pilots Association. A steering committee was appointed and was composed as follows:

Chairman: W. S. Longhurst, Canadair Ltd.

Vice-Chairman: D. H. Rogers, Avro Aircraft Ltd.

Secretary: F/L J. C. Henry, CEPE Rockcliffe.

Advisers: The chief test pilots of the RCAF, RCN and the aircraft companies in Canada; Mr. H. C. Luttman, Secretary of the C.A.I., and Mr. W. Gadzos of the Department of Transport.

Several lengthy discussions were held by this august body in the ensuing months and eventually it was decided to accept the C.A.I. proposal that the test pilots form a Section of the C.A.I. During this period, Mr. Luttman did yeoman service in acting as an adviser and as liaison between the test pilots and the C.A.I.

Finally, on the 25th November, 1956, the C.A.I. Council approved the formation of Sections within the C.A.I., which would give members with common interests a framework for discussion and action on problems concerning their particular line of work. The Test Pilots Section then became the first of these Sections.

The Executive Committee of the Test Pilots held their first meeting in Ottawa on the 15th December, 1956. The members of this Committee were the members of the original steering committee and the meeting was held to form a plan of action for the Section. Two major projects were decided upon at this meeting; investigation of the problem of standardization of flight test qualifications in Canada and the problem of limited test flying above an overcast layer in jet aircraft and increasing the safety of flight during flight tests. Committees were appointed to look into these problems and within a couple of months there should be some news on how these investigations are progressing.

The Annual General Meeting of the C.A.I. will be held in Ottawa on the 27th and 28 May. The Test Pilots Section has been allocated a half day for a business meeting and technical discussion. Election of the new Executive Committee will take place by mail and the new Executive will take office at this meeting. There will be several papers of great interest to the test pilots presented during the two days and I strongly recommend that you plan to attend.

The membership of the Test Pilots Section has been increasing steadily but there are still many who are eligible who have not applied for Section membership. The identifying qualification for the Section is as follows:

> "All members of the Institute who are, or have been for not less than two years, engaged as pilots in experimental, development, production or maintenance flight testing, shall be eligible for membership of the Section."

Applications for Section membership may be obtained from the Secretary of the C.A.I. – and remember, it costs you nothing additional to join!

IDENTIFYING QUALIFICATION

Test Pilots Section

Attention is directed to the revised Identifying Qualification for membership of the Test Pilots Section, quoted by the Secretary of the Section in the above newsletter. This supersedes the Identifying Qualification appearing on page 377 of the December 1956 issue of the Journal.

SUSTAINING MEMBERS

NEW SUSTAINING MEMBER

THE following Company has joined the Institute as a Sustaining Member:

Carriere and MacFeeters Limited.

NEWS

Decca Radar (Canada) Ltd. reports that a Decca Windfinding Radar W.F.1 has been purchased by the Meteorological Branch of the Department of Transport and is to undergo tests at Toronto to determine its suitability for operation under Canadian conditions.

This new equipment is the result of extensive research by Decca Radar Ltd., who have pioneered the application of radar to meteorological problems, and is designed for the measurement of upper winds. The prototype of the Decca Windfinding Radar underwent intensive operational trials during the 2nd World Comparison of Radio-sonde at Payerne, Switzerland, organized by the World Meteorological Organization in June, 1956, where ascents were made to 90,000 ft and above.

During the International Geophysical Year, upper air stations all over the world are cooperating to measure the velocities of winds from the earth's surface to 100,000 ft. One of these Windfinding equipments is being carried by the Magga Dan now en route to the Antarctic, to be used by members of the Royal Society International Geophysical Year Expedition, which will be established at Halle Bay for two years.

Computing Devices of Canada Ltd. and Decca Navigator (Canada) Ltd. have announced an arrangement whereby CDC assumed responsibility for installation and maintenance of Decca Navigator equipment in Canada.

The Pacific Division of Bendix Aviation Corp. holds North American sales and manufacturing rights from the Decca Navigator Company Ltd. These rights in Canada have been acquired by CDC, actively supported by the activities of Bendix Pacific and Decca Navigator (Canada) Ltd.

The Decca Navigator is a high precision navigation system consisting of a chain of ground stations which provide a hyperbolic grid system of low frequency radio signals, and marine and airborne receivers designed to interpret these signals into an accurate position. CDC engineers and technicians, with the cooperation of Decca Navigator (Canada) Ltd., are in process of installing the first Canadian land based chain located in Newfoundland. Several vessels of the Department of Mines and Technical Surveys have successfully used the system for Canadian survey purposes. Eleven chains already installed in Europe give complete coverage of the Atlantic coastline of Europe from northern Norway to northern Spain. As a result, more than 3,700 ships and aircraft based in Europe are equipped with receivers for use on the eastern side of the Atlantic, including over a thousand fishing vessels.

Potential users in Canada of the precision Decca system are shipping companies, fishing vessels, ferry boats, the RCMP, Dept. of Mines and Technical Surveys Hydrographic Survey vessels, some larger pleasure boats and tugboats. Similar equipment designed for airborne use is applicable to the operations of all types of aircraft and helicopters. The Armed Services are also potential users of Decca equipment in ships, aircraft and land vehicles.

Canadian Pacific Air Lines Ltd. have sought permission to operate a service between Canada, Portugal and Spain. The following is the text of the statement by the Minister of Transport on this subject:

Recently Canadian Pacific Air Lines applied to the government for authorization to operate a scheduled service from Montreal to Lisbon, Portugal, under the existing bilateral air agreement between Canada and Portugal, and for authorization to extend this service to Madrid if and when appropriate arrangements with the Spanish government can be made. The new service would be operated in conjunction with the present C.P.A. service from Mexico and South America to Toronto but would not carry local traffic between Toronto and Montreal.

As has been indicated in previous statements of government policy, Trans-Canada Air Lines is the Canadian air carrier designated by the government to operate trans-Atlantic air services to European points. Trans-Canada Air Lines also has had before the government proposals for the extension of its trans-Atlantic services to additional points in Europe.

The government, after considering these matters, has taken the following action: (1) C.P.A. has been designated by the Governor in Council as the Canadian carrier to operate international scheduled air services from Montreal to Lisbon and also to Madrid if and when the necessary arrangements can be made with the Spanish government; and (2) The government has reaffirmed its policy that T.C.A. is and is to be the Canadian air carrier for service to other European points not at present served by a Canadian air carrier. T.C.A. at present provides service to London, Paris and Dusseldorf, and existing bilateral air agreements authorize a Canadian service to Brussels, Copenhagen, Oslo and Stockholm. It is expected that negotiations with the Government of Switzerland will be initiated shortly looking to the conclusion of a bilateral agreement with that country.

I am not in a position to state when the carriers concerned will initiate the new services, and any announcement on these matters will be made by the airlines themselves.

During the discussions concerning the proposed service to Lisbon, C.P.A. indicated to the government that upon being licenced to operate over this new route it would apply to the Air Transport Board for permission to give up its present domestic licence for service between Winnipeg and Churchill. The selection of a carrier to operate the Winnipeg-Churchill service will, of course, be a matter for determination in the usual manner by the Air Transport Board.

SUSTAINING MEMBERS

of the

CANADIAN AERONAUTICAL INSTITUTE

1956-57

AEROQUIP (CANADA) LIMITED

AIRCRAFT INDUSTRIES OF CANADA LIMITED

ALLOY METAL SALES LIMITED

AVIATION ELECTRIC LIMITED

AVRO AIRCRAFT LIMITED

BABB COMPANY (CANADA) LIMITED

BRISTOL AERO ENGINES LIMITED

BRISTOL AERO ENGINES (WESTERN) LIMITED

BRISTOL AEROPLANE COMPANY OF CANADA (1956) LIMITED

BRISTOL AIRCRAFT (WESTERN) LIMITED

B. W. DEANE & COMPANY

CAMPBELLFORD PRECISION PRODUCTS LIMITED

CANADAIR LIMITED

CANADIAN CAR & FOUNDRY COMPANY LIMITED

CANADIAN PACIFIC AIR LINES LIMITED

CANADIAN PRATT & WHITNEY AIRCRAFT COMPANY LIMITED

CANADIAN STEEL IMPROVEMENT LIMITED

CANNON ELECTRIC CANADA LIMITED

CARRIERE AND MACFEETERS LIMITED

COMPUTING DEVICES OF CANADA LIMITED

DECCA NAVIGATOR (CANADA) LIMITED

DECCA RADAR (CANADA) LIMITED

DEHAVILLAND AIRCRAFT OF CANADA LIMITED

D. NAPIER & SON LIMITED

DORVAL METALCRAFT COMPANY

DOWTY EQUIPMENT OF CANADA LIMITED

ELECTRODATA DIVISION OF BURROUGHS ADDING MACHINE OF CANADA LIMITED

FAIREY AVIATION COMPANY OF CANADA LIMITED

FIELD AVIATION COMPANY LIMITED

FLEET MANUFACTURING LIMITED

GARRETT MANUFACTURING CORPORATION OF CANADA LIMITED

GENERAL CONTROLS CO. (CANADIAN) LIMITED

GODFREY ENGINEERING COMPANY LIMITED

GOODYEAR TIRE & RUBBER COMPANY OF CANADA LIMITED

IMPERIAL OIL LIMITED

JARRY HYDRAULICS

JET IGNITION COMPANY

LUCAS-ROTAX LIMITED

MCMILLAN INDUSTRIAL CORPORATION

MINNEAPOLIS-HONEYWELL REGULATOR COMPANY LIMITED

MOFFATS LIMITED (AVCO OF CANADA)

NORMALAIR (CANADA) LIMITED

NORTHWEST INDUSTRIES LIMITED

OKANAGAN HELICOPTERS LIMITED

ORENDA ENGINES LIMITED

PRENCO PROGRESS & ENGINEERING CORPORATION LIMITED

PSC APPLIED RESEARCH LIMITED

RAILWAY & POWER ENGINEERING CORPORATION LIMITED

ROLLS-ROYCE OF CANADA LIMITED

ROSS-AERO LIMITED

ROUSSEAU CONTROLS LIMITED

SHELL OIL COMPANY OF CANADA LIMITED

SIMMONDS AEROCESSORIES OF CANADA LIMITED

S. SMITH & SONS (CANADA) LIMITED

SPARTAN AIR SERVICES LIMITED

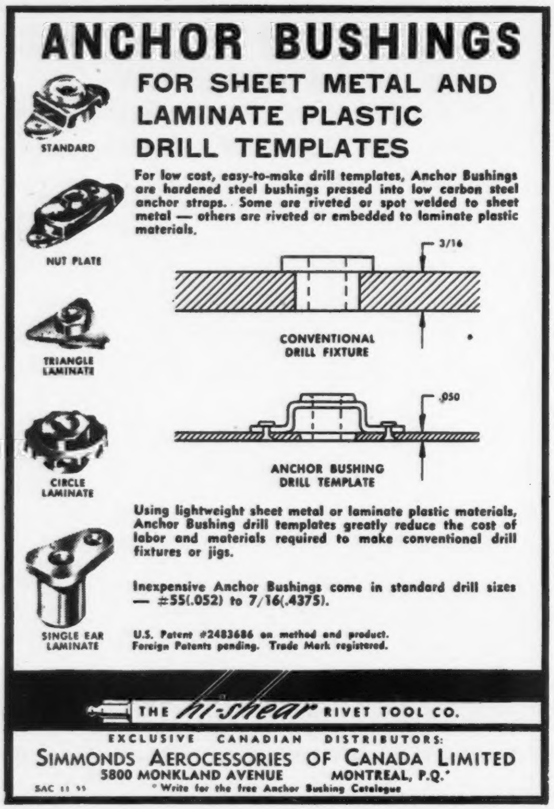
STANDARD AERO ENGINE LIMITED

THOMPSON PRODUCTS LIMITED

TRANS-CANADA AIR LINES

WALTER KIDDE & COMPANY LIMITED

YORK GEARS LIMITED



MEMBERSHIP OF THE C.A.I.

The qualifications and annual dues set out in the table below are those presently laid down by the By-laws. The rates of dues shown in brackets are those applicable to members who are also members of the R.Ae.S., I.A.S. or E.I.C. or who are resident outside Canada or the U.S.A.

The annual dues include a non-deductible subscription to the *Canadian Aeronautical Journal.*

Applications for membership must be made on the approved forms, which may be procured from the Secretaries of the Branches or from C.A.I. Headquarters. An applicant does not apply for membership in any particular grade, but each application is considered by the Admissions Committee and by the Council, who decide the grade suitable to the applicant's qualifications. On admission, the applicant is informed of his grading and the appropriate entrance fee and annual dues.

The entrance fee is $5.00, except in certain special circumstances.

Grade	Qualifications	Annual Dues
Student	Undergoing a course of study at an approved school of engineering or technology	$3.00 ($2.00)
Technician	Engaged in technical work in aviation	$5.00 ($2.00)
Technical Member	Engaged in science, engineering, research, manufacture or operation, in aeronautics or related fields, for 4 years or graduated from an approved school of engineering or science	$7.00 ($4.00)
Member	Engaged in aviation for 8 years and acquired a recognized standing	$8.00 ($4.00)
Associate	Engaged in aviation, though not qualified for technical grades	$8.00 ($4.00)
Associate Fellow	Engaged in aeronautical science or engineering for 10 years and been in responsible charge or made outstanding contribution	$9.00 ($5.00)
Fellow	Been an Associate Fellow for 1 year and attained distinction in aeronautics	$10.00 ($5.00)